GIS-ASSISTED EROSION INTENSITY MAPPING: A CASE STUDY FROM ALAKNANDA VALLEY, GARHWAL HIMALAYA

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A thesis submitted
in partial fulfillment of the requirements
for the degree of

Master of Technology

by
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...I dedicate this work to my parents and brother....

CERTIFICATE

Certified that the work presented in this thesis entitled **'GIS-ASSISTED EROSION INTENSITY MAPPING: A CASE STUDY FROM ALAKNANDA VALLEY, GARHWAL HIMALAYA'** has been carried out by **Sri Sanjoy Das** (Roll No. 9710329) under our supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

River Alaknanda draining the Garhwal Himalaya, Uttar Pradesh (India) is one of the major source rivers of the Ganges system. The Alaknanda joins with the Bhagirathi at Devprayag and is called Ganga downstream of this confluence. Several natural hazards such as landslides, mass wasting and flash floods have destroyed vast areas in the Alaknanda catchment in recent years particularly in the downstream reaches. Moreover, several multipurpose engineering projects in this region have failed due to excessive erosion and sediment production in the reservoir. A study of catchment erosion and sediment production in the Himalayan terrain has become very relevant in view of the ongoing International Decade for Natural Disaster Reduction (IDNDR). The present study is aimed at catchment-scale erosion intensity mapping and sediment source delineation using a Geographic Information System (GIS) and one of multi-criteria decision-making techniques called Analytical Hierarchical Process (AHP).

The development of the GIS model is based on categorizing the different geological processes responsible for the erosion and hence sediment production in the Alaknanda river catchment. Accordingly, different thematic maps were prepared from different data sources including remote sensing data and available published maps supplemented with field data. The analysis of the study area was done separately for two different sections namely, Srinagar-Rudraprayag section and Rudraprayag-Nandprayag section essentially due to difference in the resolution of the available data. For both sections, the thematic database includes lithological, structural, geomorphological, vegetation, drainage density, lineament density, and slope maps. These maps were prepared using digital image processing techniques supported with ground reference data. The model also incorporates the use of elevation data in the form of a Digital Elevation

Model (DEM) to determine the slope of the area. The GIS modeling involved determination of the relative importance weightage (RIW) of the controlling factors through AHP. This provided a systematic approach for assessing and integrating the impact of various factors, involving different levels of qualitative and quantitative information. Superimposition of each of the database ("layers") was made through a proper algorithm to produce the final Erosion Intensity Map. Thus, the resultant erosion intensity map of the two different sections was found to be different due to difference in the resolution of the data types used for the analysis. The erosion intensity map of Srinagar-Rudraprayag provided more detailed information about erosion and sediment production zones. The erosion intensity map of the Rudraprayag-Nandprayag section provided a much more regional-scale erosion and sediment production zones. The final maps correlate very well with field observations and other ground truth information such as landslide zones in the region.

Chapter 1

INTRODUCTION

1.1 GENERAL

Erosion and sediment production in the headwaters or upstream region of the drainage system cause a serious problem in many parts of the world, because these deteriorate the on-site natural conditions and affect the areas downstream. High rate of sediment production, especially in a mountainous terrain, is of great concern to the development and operation of various multipurpose engineering projects in these regions. The erosion processes hence need to be investigated as they instigate natural hazards such as flash floods, landslides and debris flow. Moreover, higher sediment production may reduce the water quality, cause siltation in lakes, reservoirs and canal systems. At this juncture a good, acceptable, more scientific approach towards delineation of sediment sources and planning of suitable erosion control scheme has become essential. It should also be noted that planning of any soil conservation and erosion control scheme to minimize downstream effects requires information about the sources of sediment supply to river system.

1.2 PATTERN OF SEDIMENT YIELD ON CONTINENTAL SCALE

Sediment yield is the rate of mechanical erosion, which is expressed in tonnes/km^2-yr. This sediment yield can be calculated from total suspended material (TSM) carried by a river system. In recent years various authors have estimated the sediment yield on a continental scale as well for individual basins (Garrels and Mackenzie, 1971; Holland, 1978; Milliman and Meade, 1983; Berner and Berner, 1987).

Table 1.1 shows that the sediment yield or rather the rate of mechanical erosion varies widely from continent to continent. Among the various factors controlling mechanical erosion, the relief of the drainage basin appears to be the most dominant factor as reflected by the highest sediment yield of Asia, which is having the highest mean elevation with respect to other continents

Table 1.1 Suspended sediment yield from river basins of continental scale

Continents	Sediment Yield (tonnes/km^2-yr)	Mean Elevation (km)
North America	66	0.72
South America	97	0.59
Europe	50	0.34
Asia	380	0.96
Africa	35	0.35
Australia	28	0.34

(After Berner and Berner, 1987)

Raymahasay (1973, 1986) reported a similar trend of sediment yield from major Indian drainage basins, for example, among Indian rivers; those originating in the Himalayas have relatively higher rate of mechanical erosion compared with peninsular river (Table 1.2). Apart from elevation, natural phenomenon like earthquake and landslide can cause a sudden increase in sediment load in the Himalayan rivers. Recent global reviews (Milliman and Meade, 1983; Walling and Webb, 1987) indicate that the total material transported from the land to ocean which includes the suspended, dissolved and bed load is around 19 to 20 billion tones per year. Out of the total load, the particulate load is 80 per cent and the dissolved load is 20 per cent, thus ratio of particulate load to dissolved load is 4:1. The contribution from Asia, for example, which incidentally yields maximum sediments, happens to be 6433×10^6 tones per year suspended matter and 1592×10^6 tones per year dissolved chemicals (Walling and Webb, 1987). The contribution from the major Indian rivers has been estimated to be 1209×10^6 tones per

year of suspended load and 282×10^6 tones per year of dissolved load (Subramanian, 1979). Data show that the Ganges and Brahmaputra together transport around 3 per cent of the global dissolved load to the ocean. Moreover, the combined sediment yield of these two rivers is the largest in the world amounting to 1670×10^6 tones per year (Milliman and Meade, 1983). Thus it is clear that the Indian subcontinent plays a major role in supplying fluvial sediment to the ocean. It is therefore necessary to device techniques to identify zones of sediment production within the river basin and plan relevant erosion control schemes.

Table 1.2 Sediment yield from river basins of India

River Basin	Sediment Yield (tonnes/km^2-yr)	Basin Elevation (m)
Brahmaputra	865.5	5000
Ganga	591.5	3000
Mahanadi	156.0	500
Narmada	58.7	760
Godavari	56.0	400
Krishna	42.2	420
Tapti	41.7	740
Cauvery	8.1	630

(After Subramanian, 1979)

1.3 NEED FOR SEDIMENT SOURCE DETECTION AND EROSION CONTROL STUDY

The rate of sediment yield and fluvial denudation and erosion in the upstream area and subsequent sediment transport influence downstream channel and valley development. Higher sediment yield lead to several environmental and natural disasters like flash flood, dam failure, bridge failure, land degradation along with failure of several multipurpose engineering and development projects. High rate of erosion and sediment production in the headwaters of the of drainage system present a serious problem in the

planning of large scale multipurpose engineering projects from the point of view of sediment production and siltation.

The erosion hazards, in general, cannot be completely prevented. However, the intensity and severity of their impact can minimized by firstly identifying the major zones/features acting as the potential sediment production zones in the upstream regions and then take effective measures. Very few attempts have been made toward an integrated study of catchment scale erosion mapping and sediment source delineation. Mosely (1980) carried out mapping of sediment sources in a New Zealand watershed. A purely qualitative technique was used in Harper-Avoca watershed, New Zealand and it was demonstrated that some of the well-established beliefs regarding the supply of sediments to the river system might be erroneous. The sediment supply appeared to be controlled primarily by geomorphic and geologic factors; vegetation and human interference with the ecosystem probably have a minor effect on the rate of supply. Vegetation, landcover and geomorphological map of the study area were prepared and on each of these maps the sediment sources were classified on basis of the degree of activity. Accordingly, each of these features on the thematic maps was given a qualitative "severity ranking". Thus although the technique was qualitative, the procedure provided useful information on the location of major sources of sediments on the basis of relative importance of each features and subareas.

Gunawan et al. (1994) combined the Land Erodibility Assessment Methodology (LEAM) with a Geographic Information System (GIS) to model land erodibility/soil erosion potential in the tropical rain forests of Sumatra, Indonesia. Land erodibility was assessed using only three major characteristics: (a) slope hazards, (b) rainfall erosivity risk and (c) soil erodibility. Indices based on topography, rainfall, and soil type having

spatial distributions were represented as various GIS layers. Finally, a land erosion potential map was prepared by registration of the thematic layers in a GIS environment.

Narayan *et al.* (1983) carried out an erosion intensity study in the mountainous watershed of the Ravi River in the Himalayan region. The factors controlling intensity were identified as geomorphology, mean ground slopes and the lithological cum structural state of the bedrock. The technique involved detailed field investigations, evaluation and mapping in a small area around Chamba region in the Ravi catchment. The major geomorphic features mapped were fill-cut and strath terraces, alluvial fan, landslides, small talus cones and debris flow deposits. A slope map prepared from the topographic map was divided into several classes. Lithologically, the study area consists of Phyllite, Quarzite, Slate, Limestone, Conglomerate and Granite. A structural state map was prepared delineating 'shattered rocky zones' and 'unshattered rocky zones'. Qualitative indices were designated to various classes of geomorphic, mean ground slopes and lithological cum structural state maps of the region. Then these thematic maps were overlaid and the Erosion Intensity (EI) values of the individual factors were multiplied to obtain the composite Erosion Intensity Index (EII). The logarithms of these composite EII were computed and the final map thus obtained was classified into several categories and hence an erosion intensity map based on these categories was prepared.

The available information indicates that over the years few attempts on erosion intensity and sediment source determination have been made. The techniques followed were mostly used very few factors controlling erosion and sediment production are qualitative. Narayan *et al.* (1983) used an integrated approach over a small area in the Himalayan watershed. But no such work has been done on the major Himalayan rivers like Ganges or Brahmaputra having one of the largest sediment yields in the world.

Further, as this work was completely field-based, its applicability is limited to small areal extent.

The advent of digital remote sensing and GIS techniques have remarkably enhanced the applicability of integrated, multi-data approach for erosion studies. Apart from providing synoptic coverage, repetitive data and high spatial resolution, the technique also overcome the difficulty of inaccessibility of many parts of mountain terrain as the Himalayas. Accordingly, the present study has been undertaken to utilize remote sensing data coupled with ground maps to identify zones of sediment production in the parts of Garhwal Himalayas, Uttar Pradesh.

1.4 AREA OF STUDY

The present study has been carried out in Srinagar-Nandprayag area, which is a part of Alaknanda valley in Garhwal Himalaya (Figure 1.1), Uttar Pradesh. The study area falls between the latitudes 30°05' to 30°25' and longitude 78°45' to 79°20' and encompasses an area of 1250 sq. km. The selection of this study area was primarily governed by the need of a reconnaissance study of the different geo-hazard zonation in the area in the view of failure of many upcoming multi-purpose developmental projects, frequent flash floods, failure of dams due to reservoir siltation problem and the necessity of keeping the strategically important Rishikesh–Badrinath road functional. So such erosion intensity and sediment source study of this region would become relevant contribution in this on going International Decade for Natural Disaster Reduction (IDNDR)

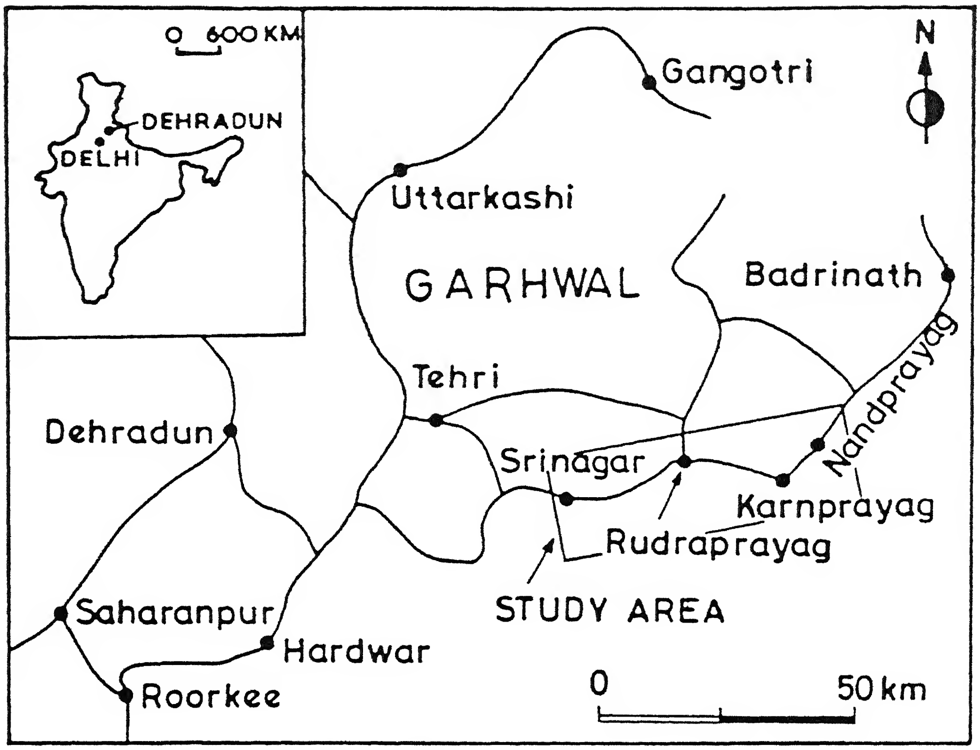


Figure 1.1 Location map of the study area

1.5 OBJECTIVE AND SCOPE OF STUDY

The ongoing development activities and several multipurpose engineering project proposals in Himalayas call for identification of erosion susceptibility zones and delineate major sediment production zones. The present study was aimed at developing a methodology for regional-scale sediment source delineation and erosion intensity mapping technique with the help of remote sensing data supported by field investigation in a GIS environment. The procedure has taken into account the relative importance of a variety of geological processes responsible for sediment production in the Alaknanda catchment.

The specific objectives of the project are listed as follows:

(i) Identification of factors controlling erosion and sediment production in the Alaknanda catchment.

(ii) Establish the utility of remote sensing coupled with ground data for erosion studies in a mountainous terrain.

(iii) Development of multi-source database of the different factors controlling sediment production.

(iv) Development of integrated GIS model using multi-criteria decision-making technique called analytic hierarchical process (AHP).

(v) Preparation of sediment production/erosion intensity map for parts of the Alaknanda catchment, Garhwal Himalaya.

The sequence of investigation for achieving the aforesaid objectives is schematically shown in Figure 1.2 and described as under:

(a) Field investigation

Field investigation in the study area was carried out to identify the factors controlling the rate of erosion in the region. In general, slope of the drainage basin, geomorphology, lithology, structure, vegetation, and drainage density were considered to be the important factors. The factors like climate and rainfall over the study area have been considered to be constant.

(b) Map analysis

The available geological maps and topographic sheets were analyzed to derive information on lithology, drainage, and slope. The data were converted into digital form through scanning and on-screen digitizing to be available for GIS analysis.

(c) Remote sensing data analysis

Digital remote sensing data was analyzed using IDRISI image-processing software to derive information on geomorphology, vegetation, and geologic structure supported with available maps and ground truth verification.

(d) GIS analysis

All maps/data obtained through image processing and digitization were analyzed in a GIS environment for development of a suitable algorithm for multi-criteria decision-making for identification of erosion intensity and sediment production zones. A technique for quantitatively assessing the hierarchical weightage of each factor controlling sediment production was used based on the Analytical Hierarchical Process (AHP).

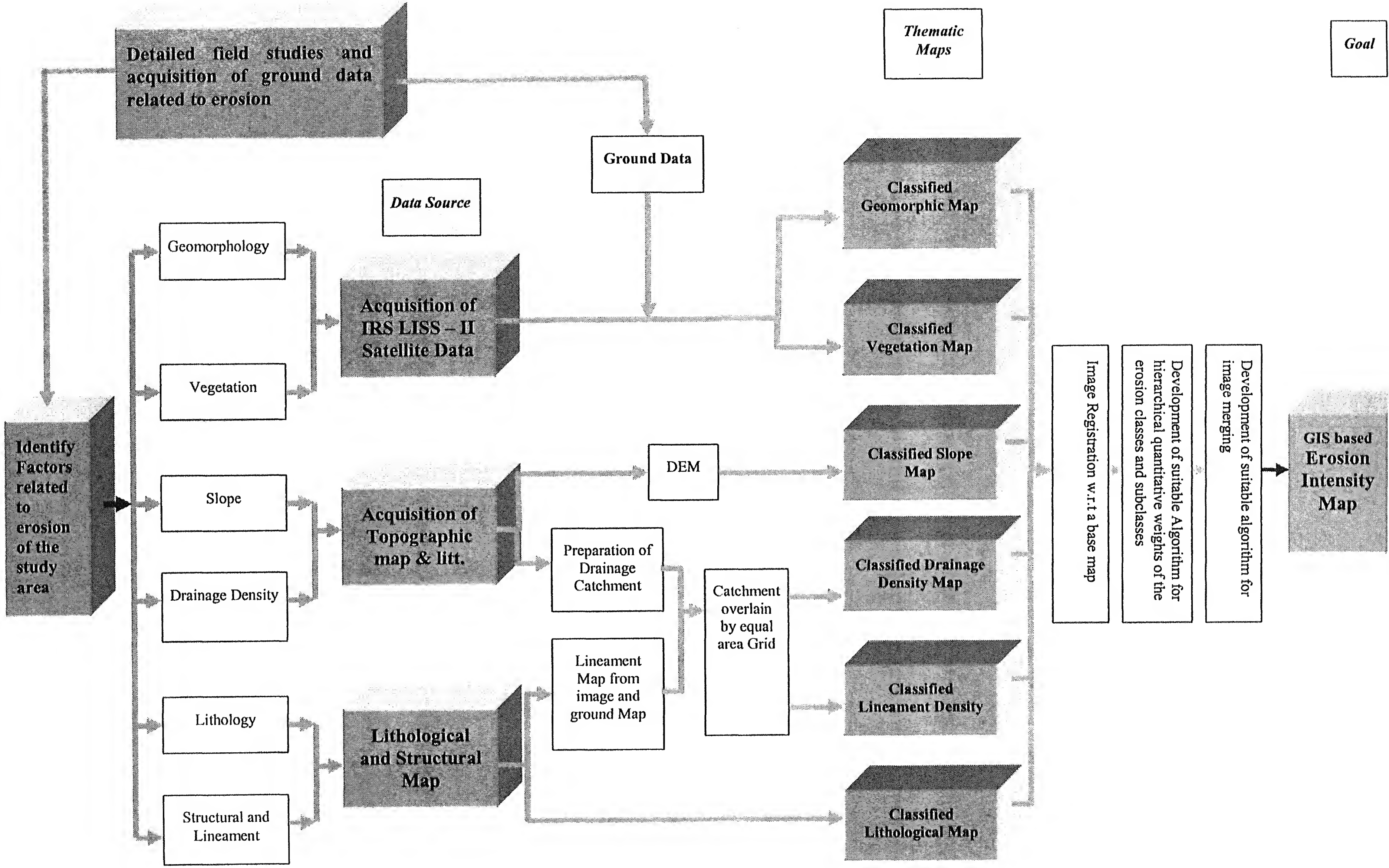


Fig 1.2 Flow diagram for erosion intensity mapping

1.6 THESIS OUTLAY

The present thesis has been organized in six chapters. Chapter 1 introduces the subject area of the thesis and highlights the objectives and scope of study. This chapter also includes the review of available literature on the studies related to the mapping of the erosion intensity/sediment production zones from different parts of the world. Chapter 2 provides the background information on the regional geology of the study area, including lithological description of different geological formation as available from published literature. Major structures including faults and lineament are also described. Available information on the geomorphological units within the study area is also provided.

In chapter 3, the geomorphological field investigation in the Alaknanda catchment is described. Field description of the different geomorphological features present in the study area is provided and their susceptibility to erosion has been evaluated qualitatively. Chapter 4 deals with the techniques involved in the preparation of thematic layers using remote sensing data and available maps supported with ground-truth information. This chapter also deals with major interpretation from each layer from the viewpoint of sediment production.

Chapter 5 discusses the algorithm involved in ranking the different thematic layer using AHP. The final GIS model for generating a map of erosion intensity/sediment production zones has also been presented in this chapter. Finally, Chapter 6 summarizes the work presented in this thesis.

Chapter 2

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING OF THE ALAKNANDA CATCHMENT

2.1 GENERAL

The Alaknanda Valley falls in the Lesser Himalayas of the Garhwal Himalayas (Figure. 2.1; Gansser, 1964). The Lesser Himalayan zone, in general, consists of a series of ridges and spurs divided by deep valleys. The average relief of the ridges ranges from 1500m to 3000m. The Main Boundary Thrust (MBT) separates the lesser Himalaya from the Sub-Himalaya (av. Relief 400-800m) and the Main Central Thrust (MCT), a zone of intense shearing, separates the Lesser Himalayan rocks from the high-grade metamorphics of Great Himalayas (average relief of 4800-6000 m). The high peaks in the Great Himalaya are separated by the transverse gorges of the major rivers of the area. The zone beyond the Great Himalayas is the Tibetan and Tethys zone which is bordered in the north by an Ophiolite Suite associated with Indus Tsangpo Suture.

A geological map of the Garhwal Himalaya was first prepared by Hurbert (1842) followed by Middlemiss (1887), Heim and Gasser (1939) and Auden (1949).. During the last two decades, several workers have carried out studies on geology, tectonic and stratigraphy of various pats of Garhwal – Kumaun Himalayas (Jain, 1971; Salkani, 1971, 1972; Rupke, 1974; Kumar et al., 1974; Kumar and Agarwal, 1975; Valdiya, 1978, 1980; Fuches and Sinha, 1978; Srivastava and Ahmad, 1979, Virdi, 1986; Roy and Valdiya,

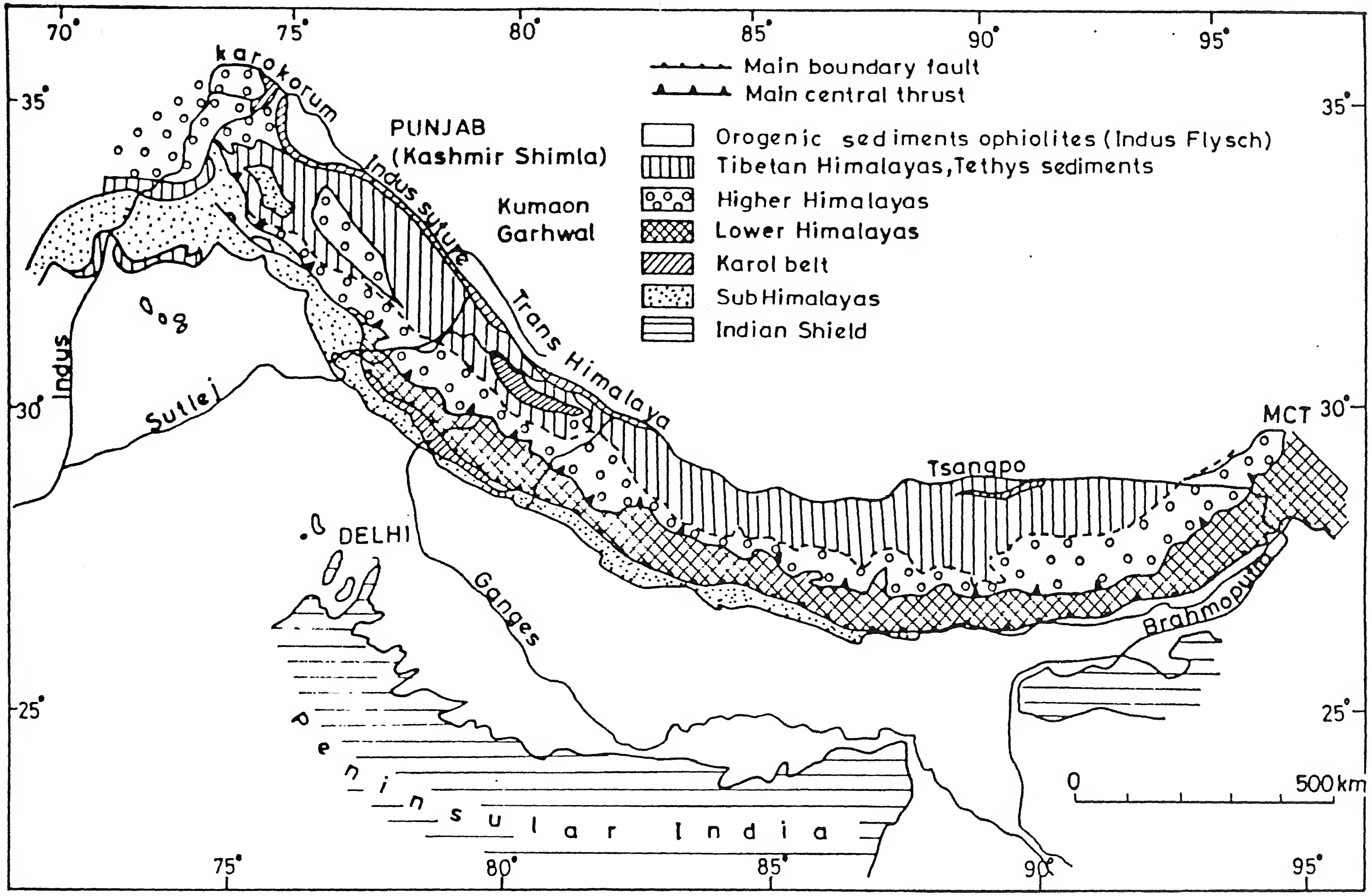


Figure 2.1 Longitudinal sub-divisions of the Himalayas (after Gansser, 1964)

1988; Thakur, 1993). This chapter presents a brief account of geological and geomorphological setting of the Alaknanda catchment based on the available literature.

2.2 REGIONAL GEOLOGY OF THE ALAKNANDA VALLEY

River Alaknanda, during its course of journey, cuts across all the litho-tectonic units of Garhwal Himalayas, ranging in age from Precambrian to Neogene. The most recent regional-scale lithostratigraphy of the region has been given by Valdiya (1980) as per which the Kumaun Lesser Himalayas has been divided into four major litho- tectonic units. Each of these units is characterized by distinct lithological composition, stratigraphic succession, structural pattern and magmatic history. Four litho-tectonic units given by Valdiya (1980) are as follows:

I. The Autochthonous unit of the Damatha and Tejam Groups of Precambrian sedimentary formation exposed in the vast window in the inner (Northern) belt of the Lesser Himalayas

II. The Krol Nappe of the outer (southern) Lesser Himalayas constituting the Jausar and Mussoorie groups of sediment of possibly Paleozoic ages. In the Lesser Himalayas the Krol Nappe is considerably attenuated and is represented by Berinag Nappe made up of a litho-stratigraphic unit which also form a part of the Jausar group of the Krol Nappe

III. The Ramgarh Nappe and its extensions that cover parts of the Beringnag and Krol Nappes, consisting of a lithology that resembles the upper part of the Damatha group of the autochthonous zone

IV. The Almora Nappe, its klippen and the root at the base of the Greater Himalayas, made up of medium – grade metamorphics intruded by syntectonic and profoundly deformed Granitic suite. The root of the Almora Nappe has been thrust over by a litho - tectonic unit composed of rather high-grade metamorphics of Precambrian age. The litho - tectonic unit of the Kumaun Himalayas belongs to the great Himalayan realm. The other unit is formed of the later Tertiary sediment of the Siwaliks in the Sub – Himalayas that has been sharply severed from the lesser Himalayas by Krol (Main Boundary) Thrust.

A number of investigators have carried out geological and other related studies in the study area. The differences of opinion among different workers lie primarily in the stratigraphic succession. Table 2.1 provides a summary of the stratigraphy of the Kumaun Lesser Himalayas given Valdiya (1980).

Table 2.1: Tectonic Succession of the Kumaun Lesser Himalayas

	Outer Lesser Himalayas	Inner Lesser Himalayas
		Vaikrita Group (Early Precambrian)
		---------Vakrita (Main Cental) Thrust---------
	Gumalikhet Fm.	Musiari Fm.
Almora Group	Champawat Granodiorite	
	Saryu Fm.	
	--------*Almora Thrust*------	-------------*Munsiari Thrust*---------------------
Ramgarh Group	Debguru Porphyroid	Bharkot and Bhatwari Unit
	Nathu khan Fm.	
	-------*Ramgarh Thrust*-----	------------*Bharkot – Bhatwari Thrust*---------
Sirmur Group	Subatu Fm. (Lr. Eocene)	
	Singtali Fm. (Paleocene)	
Mussoorie Group	Tal Fm. (Permian)	
	Krol Fm.	
	Blaini Fm.	
Jausar Group	Nagthat Fm.	Berinag Fm.
	Chandpur Fm.	
	Mandhali Fm.	
	-----------*Krol Thrust*--------	------------*Berinag Thrust*--------------------
	Subathu (Lr. Eocene)	
Damatha Gr.	Rauthgara Fm.	
	Chakrata Fm.	

(Adopted from Geology of Kumaun Himalaya, Valdiya, 1980)

For the present study, the lithological characteristics and the structure of the area only are of major concern and not their stratigraphic position. The geological map of the Srinagar–Nandprayag area (Valdiya, 1980) shown in Figure 2.2 has been used for present study. Table 2.2 summarizes the lithological characteristics for the Alaknanda catchment.

2.3 STRUCTURES AND TECTONICS

Three almost parallel major faults, Main Central Thrust (MCT), Alaknanda Fault and North Almora Thrust (NAT) have traversed the Alaknanda valley. The Garhwal group of rocks has been sandwiched between the North Almora Thrust and the Alaknanda Fault. The major structural feature of the study area is represented by the NAT. In addition, there are major and minor faults in this area. The NAT separates the Pauri and Khirsu Formations of the Dudatoli Group from the Garhwal Group of rocks. It has been traced to the Bhagirathi and Yamuna valleys (Jain, 1971; Agarwal and Kumar, 1973) in the north west and to the Kali river (Mehdi et. al., 1972) in the south east.

The NAT is termed as Srinagar Thrust (Mehta, 1971) and Srinagar Shear (Bhargava, 1972) in Alaknanda valley and Dharasu Thrust in the Bhagirathi valley (Jain, 1972). This thrust is trending WNW – ESE and dipping southerly at high angle. According to Srivastava and Ahmad (1979) the North Almora Thrust in the study area hades northwards, but elsewhere it dips southward also. Thus, it is a sub – vertical zone of dislocation. As a result, it swings sometimes towards north and sometimes south. However, the southern side is down thrown side of this thrust. In the study area the thrust crosscuts the Alaknanda valley at Koteswar and is characterized by a wider shear zone. Fragment and pulverized materials of quartzite and phyllites, more like schists, have been

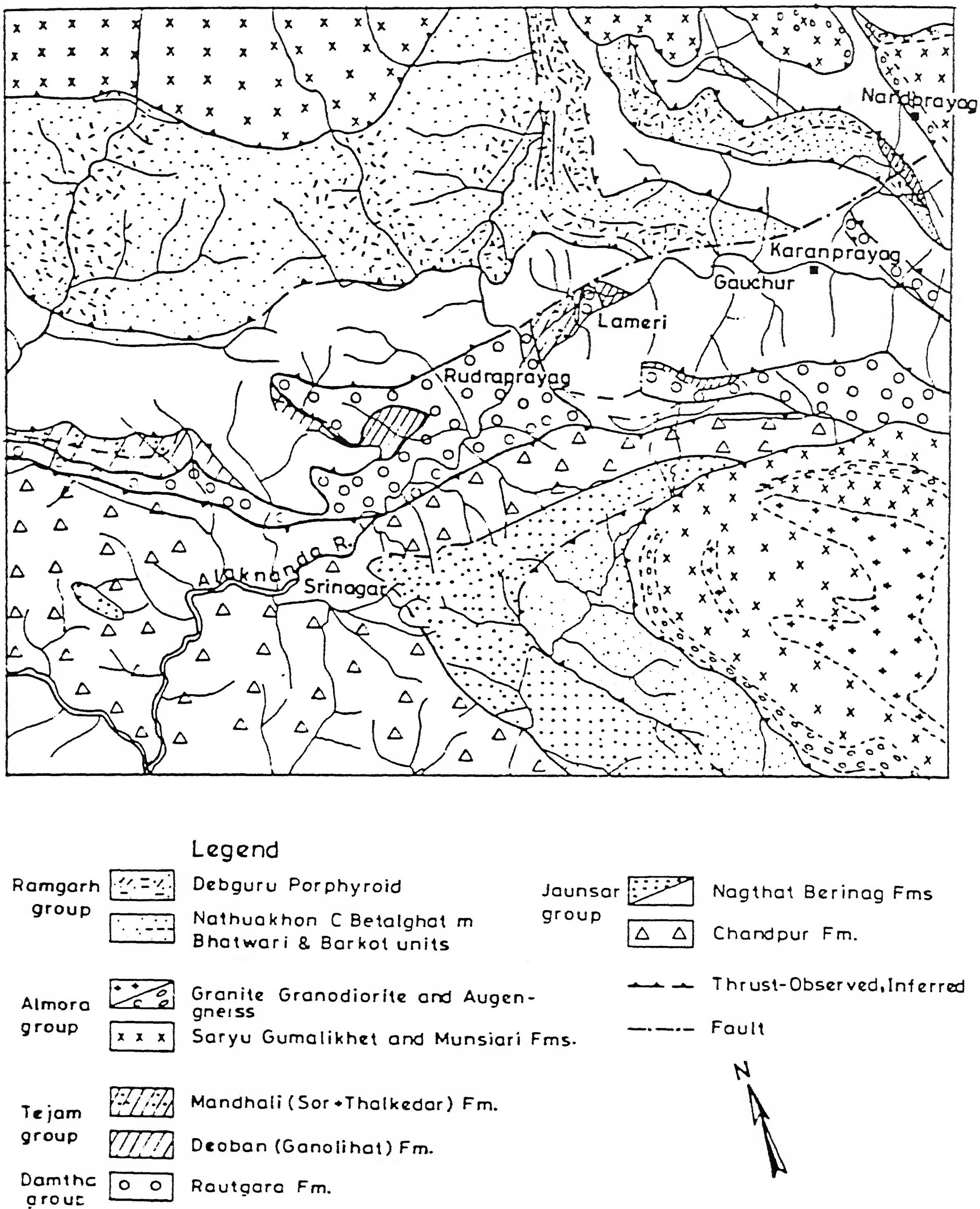


Figure 2.2 Geological map of Srinagar-Nandprayag area (after Valdiya, 1980)

Table 2.2 Lithological classification: Alaknanda catchment

Group	Formation	Lithological Characteristics
Almora	Granite-Granodiorite Augen Gneiss	- Munsiari formation predominantly of augen gneiss (granitic to granodioritic) - Profoundly affected by mylonitisation and retrograde transformation. - Compared to Almora group the Munsiari formation greater volumes of granitic rocks (porphyroblastic).
	Saryu Fm.	- Black carbonaceous phyllite alternating fine-grained biotite rich graywacke. - Carbonaceous phyllite to graphitic schist and graywacke to biotite – rich semischist transformation common
Ramgarh	Nathukhan	- Phyllite, locally schistosed, alternating or intercalated with fine grained sericitic flaggy quartzite and metasiltstone.
	Debguru porphyroid	- Quartz porphyry and granite porphyry - Rocks are structurally complex showing extensive amount of mylonitization, shearing and foliation with retrograde tranformation of the constituent mineral - Granitic bodies are centrally unfoliated, conspicuously porphyritic (granite porphyry) with rectangular phenocryst of potash feldspar - At places the granite porphyry is highly gneissosed showing post-crystalline deformation.
Jausar	Naghthat – Beringnag Fm.	- Quarztarenite (othoquartzite) locally pebbly or orthoconglomeritic, and interbedded slate. - Phyllite, quartzite and penecontemporaneous basic volcanics as essential components of the Nagthat lithology. - Beringnag lithology is similar, in the respect of the occurrence of sizable proportion of penecontemporaneous lava flows and tuffites.
	Chandpur Fm.	- Phyllite, metasiltstone and very fine grained wackes, with local metavolcanics, low grade metamorphism.
Tejam	Mandhali Fm.	- Phyllites or slates interbedded with marmorized and plastically folded limestones and a variety of paraconglomerates
	Deoban Fm.	- Extensive succession of the stromatolite-bearing, cherty Dolomite, dolomitic limestone and slates.
Damatha	Rauthgara Fm.	- Deeply oxidized oxidized slates, metasubgreywacke, sublitharenites lenses of boulder conglomerates. - Occurrence of the basic volcanic and intrusive with surprisingly little metamorphism
	Chakrata Fm.	- Thick succession of purple, dark green, greyish green and grey graywackes often micaceous and siltstones rhythmically alternating with similarly colored slates,

seen along this thrust zone. The evidence of thrusting was found to the westward of Koteswar across the river. as reported by Doval and Saklani (1980).

There are few other important faults present in the area. One of these is the Kailasaur fault striking NW – SE in the eastern part but swinging NE – SW in the western part. In the area, the fault is offsetting the Karnprayag metavolcanic and has been offset by the Narkota fault trending NW – SE at Narkota. The another major fault is the Ganji Fault trending NNW-NSE near Sera.

There are several anticlinal and synclinal structures in the area. One major anticline trends ENE – WSW (Figure 2.3) which is delimited by NAT in the west and the Alaknanda fault in the east. This is a doubly plunging fold due to which the Dhari metavolcanics close on both sides (Agarwal an Kumar, 1975). Another anticline of doubly plunging nature is the Syari Anticline, the core of which is composed of slate and dolomite. The Syari anticline and the Satni syncline are truncated against the Ganji fault.

2.4 GENERAL GEOMORPHOLOGY OF THE STUDY AREA

The River Alaknanda, rising at the Mana pass, and the River Bhagirathi originating from Gaumukh of the of the Gangotri glacier, join at Devprayag to become Ganga. Dhauli, Birehi, Nandakini, Pindar and the Mandakini are the main tributaries of the Alaknanda. The small streams (gad) and the ravines (gadera) feeding the main rivers, flow parallel to the structural strike of the and drain the area eastward. The Ganga system in the Garhwal Himalayas thus comprises of Alaknanda followed by Bhagirathi, Mandakini, Pindar, Atta Gad and Jalkhur.

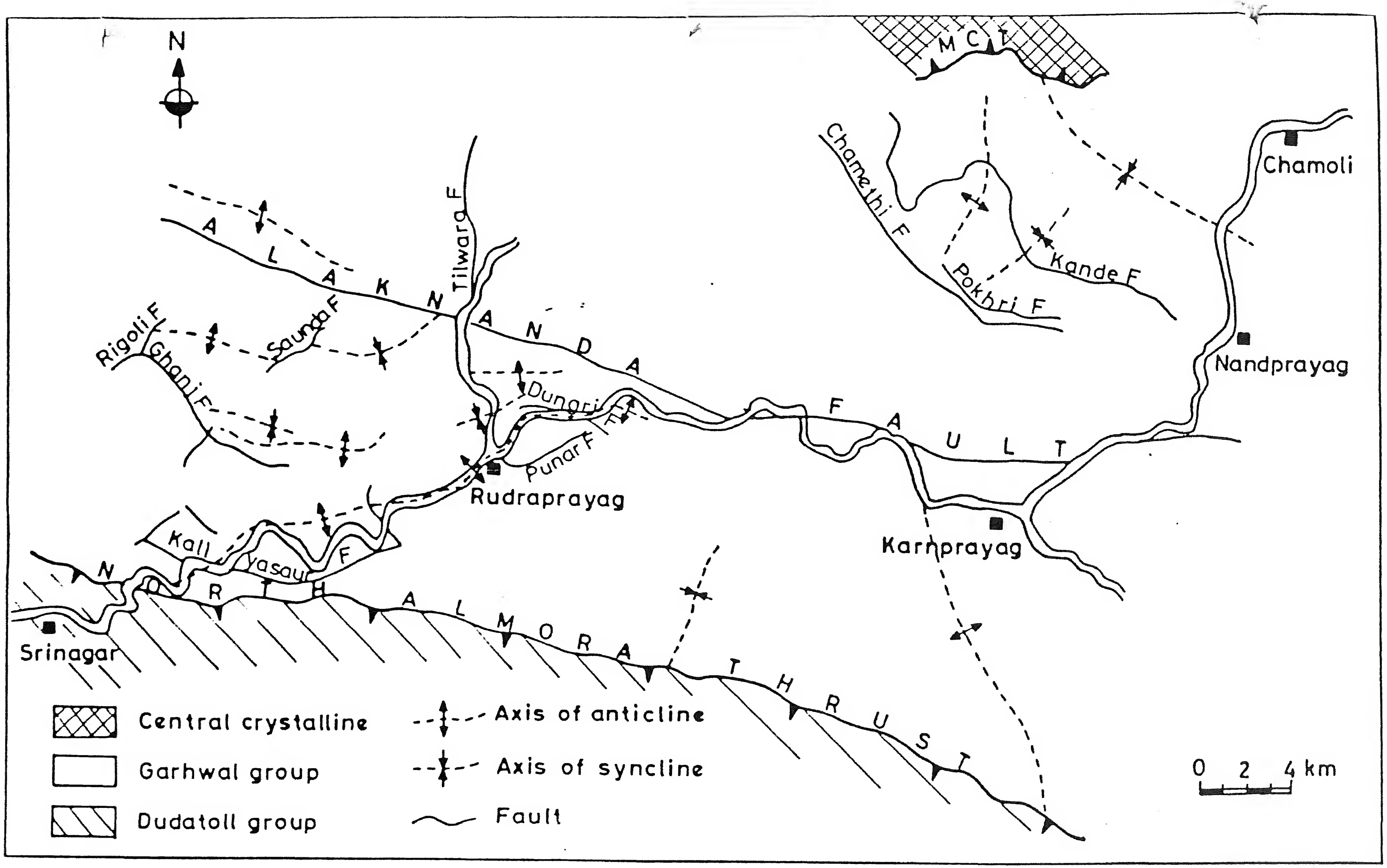


Figure 2.3 Structural map of Alaknanda catchment (after Kumar & Agarwal, 1975)

The terraces are one of the most conspicuous features in the Alaknanda valley which dominantly belong to three domains: glacial, fluvio-glacial, and fluvial deposits. The streams generally emerge from the different glaciers and descend in sinuous to meandering channel pattern. The Alaknanda shifted its course abandoning its old channel and is now flowing through a gorge. In their course they traverse through deep gorges leaving terrace representing different phases of Quaternary sedimentation. Sratigraphic succession of terraces and sequential stages of valley development in the Ganga system of Garhwal Himalayas been worked out by earlier workers (Khan et al, 1982). There is a continuous decrease in the rate of upliftment of Himalayas from early to late Holocene, as evidenced by the conspicuous disposition of the older terraces and convergence of younger terraces all along the valley (Fig. 2.4).

2.4.1. Glacial terraces

In the upstream region of the major valleys of Alaknanda, Bhagirathi, Mandakini and Pindar, conspicuous terraces have been observed at the higher elevations. The Glacial sediments include a heterogeneous mix of angular and sub angular boulder and cobbles, cobbles, pebbles and fine to very fine sand. The fabrics do not exhibit any preferred orientation (Khan et al, 1982).

2.4.2. Fluvioglacial Terraces

Fluvio-glacial terraces are noticed in Alaknanda, Bhagirathi, Pindar and Mandakini, sandwiched between terraces of glacial and fluvial domains. The fluvio – glacial terraces consists of reworked sediments from the morainic material and are characterized by heterogeneous association of rock fragments which display moderate

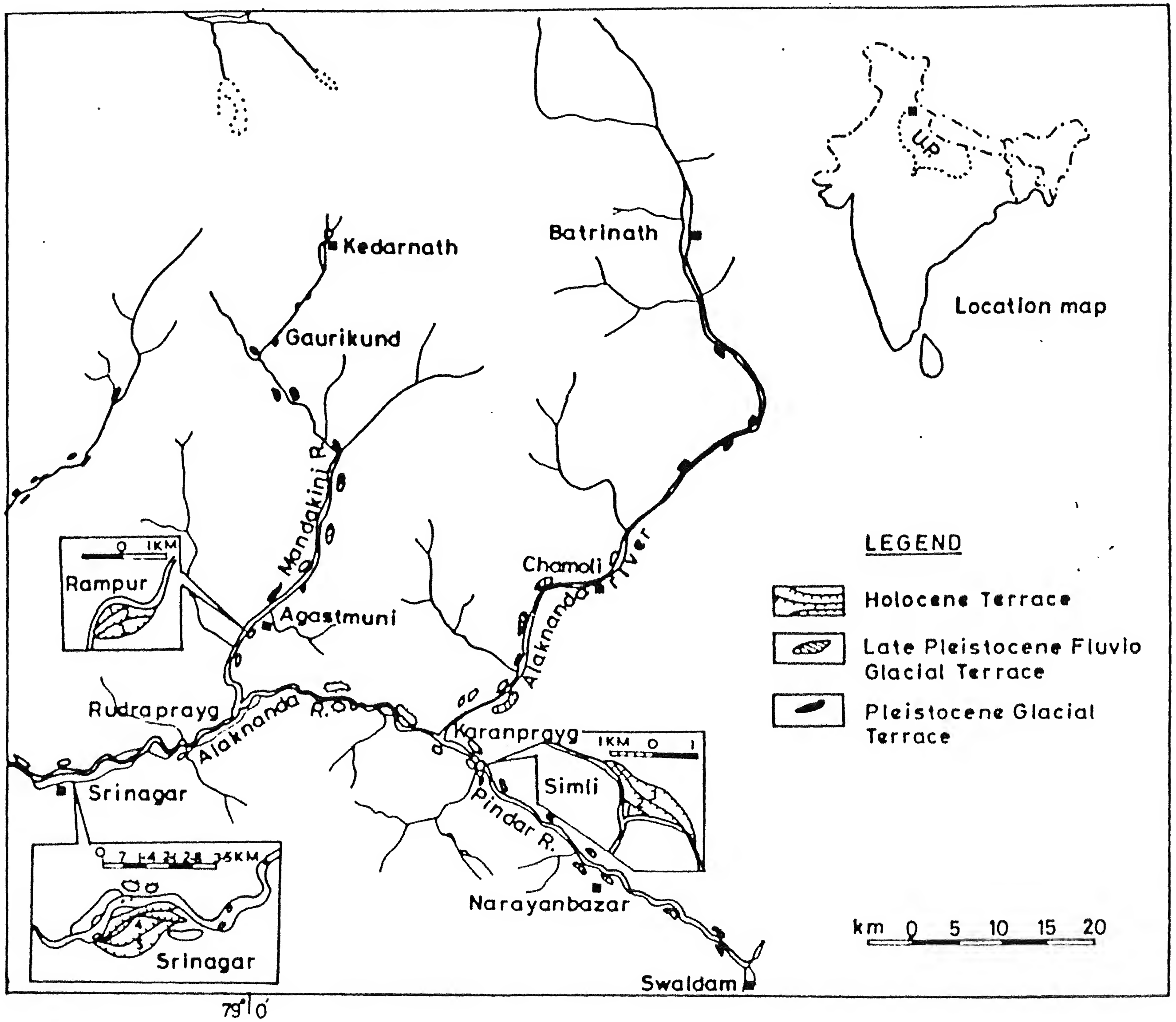


Figure 2.4 Location of major terraces along Alaknanda catchment

(after Khan et.al, 1982)

degree of sphericity and roundness, poor stratification, very poor preferred orientation pattern and devoid of cyclic sedimentation. The sand particles of the fluvio-glacial domain in general are coarse grained, moderate to poorly sorting which is an improvement over their glacial counterpart (Khan et. al, 1982).

2.4.3. Fluvial Terraces

Fluvial terraces are very well developed along both flanks of the valleys. They represent the former valley floor and flood plains that were abandoned by the channel with time. The full sequence of the terrace is rarely preserved at all places. The terraces are both paired and unpaired. The terraces comprise of boulders, cobbles and pebbles of quartzite, granite, gneiss, limestone, slate, phyllites, schists and some basics rocks in coarse to medium sands. Moreover the terraces are associated with the river bends in this area so, the extent of the individual terrace surface is long or short depending on the radii of the curvature of the river bend (Khan et al, 1982). The significant and well-developed terraces along river Alaknanda are located at Gaucher, Nagrasu, Lameri, and Srinagar. As postulated by Khan et. al (1982), the Alaknanda river has formed six prominent terraces, besides the present day flood plain (AT_0). They have been designated as AT_0 to AT_6. The AT_6 is the oldest of the terrace and the AT_1 is the youngest separated by scarps. These terraces are both of depositional and erosional in nature and are both paired and unpaired. They show convergence and divergence in their relative disposition along the length of the valley. Around Gauchar and Nagrasu the conspicous development of these terraces is restricted to the south of the left bank within the meander of the river. Around Srinagar some of the terraces show pairing. The Alaknanda reaches Srinagar Valley with a wider shape and a broader shape.

Chapter 3

FIELD INVESTIGATION IN THE ALAKNANDA CATCHMENT

A detailed field investigation from Srinagar to Nandprayag, Garhwal Himalayas, U.P, along the Alaknanda valley was carried out in April-May, 1998. The basic aim of the field work was to identify the main geological and geomorphological processes and features that are acting as the principal source of sediment supply to the Alaknanda catchment. A qualitative assessment of the relative importance of the factors from the viewpoint of sediment production and erosion characteristics was also made. This information/observation was later used to decide upon the statistical ranking of features/process in GIS analysis in Chapter 5.

3.1 GENERAL GEOMORPHOLOGY OF ALAKNANDA VALLEY

The Alaknanda valley is surrounded by steep hard rocks and appears like a typical gorge in the Srinagar-Karnprayag section. The V-shaped valley between Srinagar and Karnprayag (Plate 3.1) indicated that the fluvial processes played a dominant role in shaping the valley in this stretch. The valley gradually opens up upstream of Karnprayag. The valley widening becomes more distinct upstream of Nandprayag, where it is typically U-shaped (Plate 3.2) indicating influence of fluvio-glacial processes in this reach.

Apart from this general trend, the valley exhibits narrowing and widening at shorter intervals throughout its reach between Srinagar to Nandprayag. The valley widening generally takes place where the gradient of the river bed is probably decreasing.

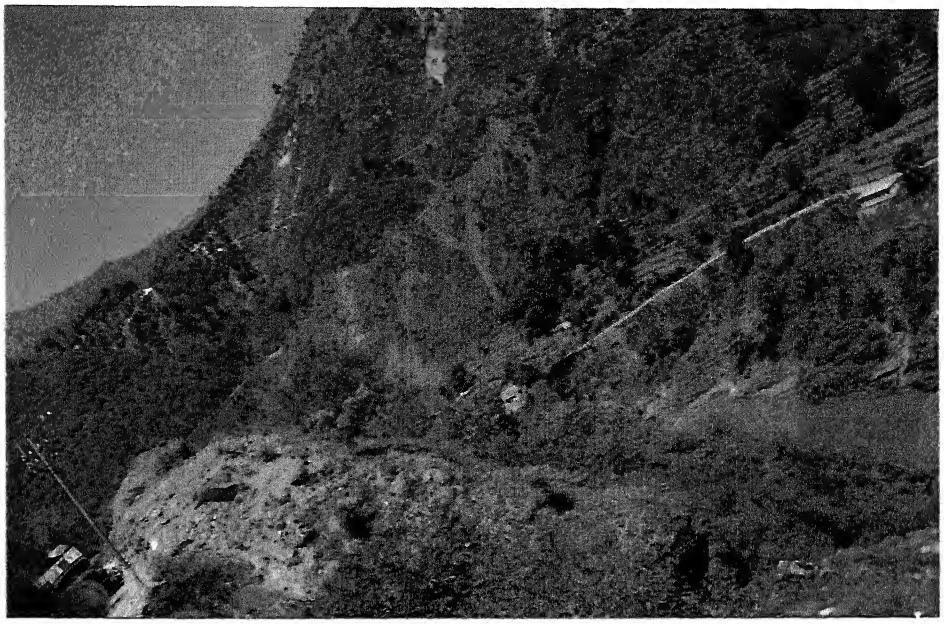


Plate 3.1 Typical V-shaped valley of Alaknanda river
Location: 1 Km upstream of Rudraprayag, Rudraprayag-Karnprayag section

Plate 3.2 Typical U-shaped valley of Alaknanda river
Location: Nandprayag

At such regions, river velocity and discharge are found to be low. Hence in such regions the valley cutting by erosion activity also decreases. Under such circumstances, where the discharge as well as velocity of the river decreases, the sediment load carrying capacity of the river water obviously also decreases. So at such locations the river water drops the sediment load. Thus, such wide reaches of a valley become the regime of sediment deposition, which are also identified and verified in the field (Plate 3.3). Valley narrowing takes place where the valley floor gradient increases. The river discharge at such locations increases considerably and hence the valley cutting by erosion activity also increases. So they are the regions from where sediment supply takes place. This sort of regular change in the gradient of the river bed may be due to the presence of some structural discontinuities near the river along which some relative downward or upward movement has taken place. Normally, valley widening and narrowing occurs alternatively, and therefore, they act as alternate sediment supply and sediment deposition regimes. At Srinagar, the Alaknanda valley becomes widest and shows large amount of sediment accumulation in the form of channel bars and side bars.

The Alaknanda river shows clear evidences of channel avulsion at many locations due to sedimentary as well as tectonic readjustments. One such avulsion event was observed at a location 1 km downstream of Kaliasaur landslide (Plate 3.4). At this location, the exposed valley walls on the right bank of the river comprise of bedded rocks, which are highly fractured and jointed. Due to tectonic movements, a large block of the bedded rock may have got detached from the main rock mass and fell into the earlier channel along with large amount of rock debris. Thereafter, the original channel got filled up with sediments and the river diverted into a new channel by headword erosion. At several other locations along the Alaknanda valley similar channel avulsions were observed.

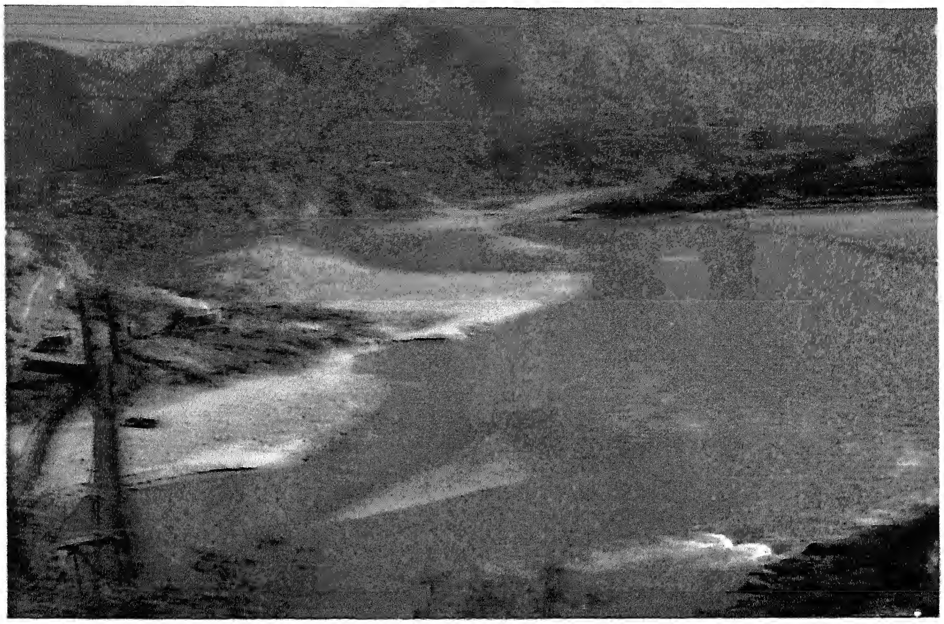


Plate 3.3 Valley widening and sediment accumulation in the form of channel bars and sidebars, Alaknanda river.
Location: Srinagar

Plate 3.4 Channel avulsion in Alaknanda river
Location: Near Kaliasaur Landslide

3.2 MAJOR GEOMORPHOLOGICAL FEATURES

Major geomorphic features that are acting as potential sediment production zones in the study area were identified during field investigations. They include terraces/riparian slip zones, gullies, alluvial fans, reworked bars etc. The following sections present a brief discussion of these features as observed in the field.

3.2.1 Terrace/Riparian slip

The fluvio-glacial terraces present all along the Alaknanda Valley (discussed in Chapter 2) were observed to be potential sediment supply zones mainly in the form of 'riparian slip'. Riparian slips are caused by fluvial undercutting and subsequent removal of support from the valley sides or terraces, causing mass movement downslope (Plate 3.5). In the entire stretch of the study area from Srinagar to Rudraprayag, riparian slips are very common features, wherever terraces are present. They continuously supply additional sediment to the Alaknanda river channel. Plate 3.6 shows riparian slip in unconsolidated material of the terrace.

At many locations, concrete as well as pebble dykes have been constructed along the Alaknanda river bank to reduce the undercutting by the river particularly at sharp bends such as the one shown in Plate 3.7.

3.2.2 Gully

Most parts of the Alaknanda Valley are dissected by steeply sloping gullies that were perhaps initiated as debris avalanches. Continuous frost action, rainfall, and wind action enlarge these debris avalanches which gradually develop into gullies (Plate 3.8). In headwaters region of the catchment, deep V-shaped gully systems are incised in many places into the shattered bedrock. So gullies are one of the major geomorphological

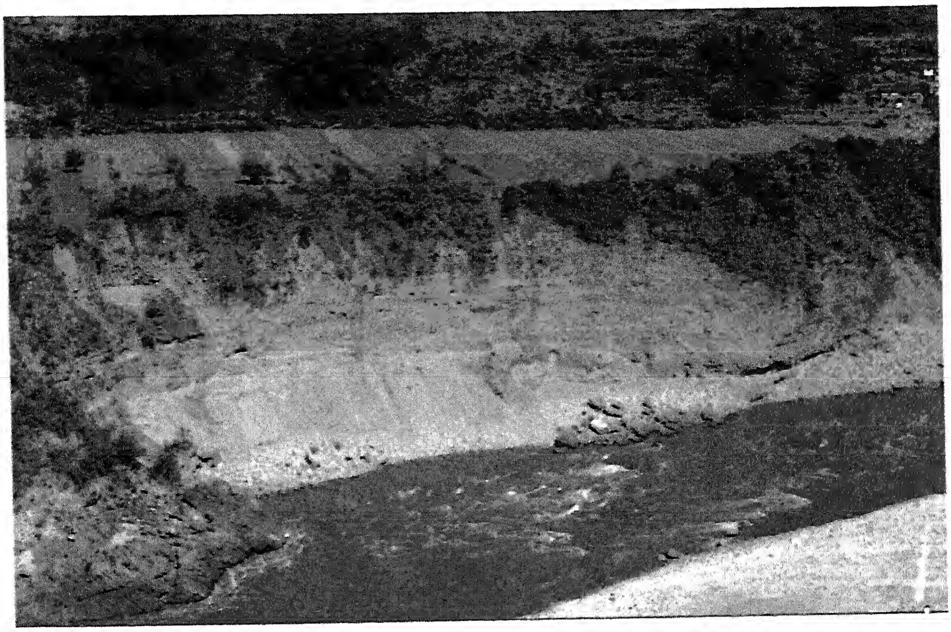


Plate 3.5 Undercutting of terraces by fluvial action and subsequent downslope mass movement
Location: Dhari Village, Srinagar-Rudraprayag section

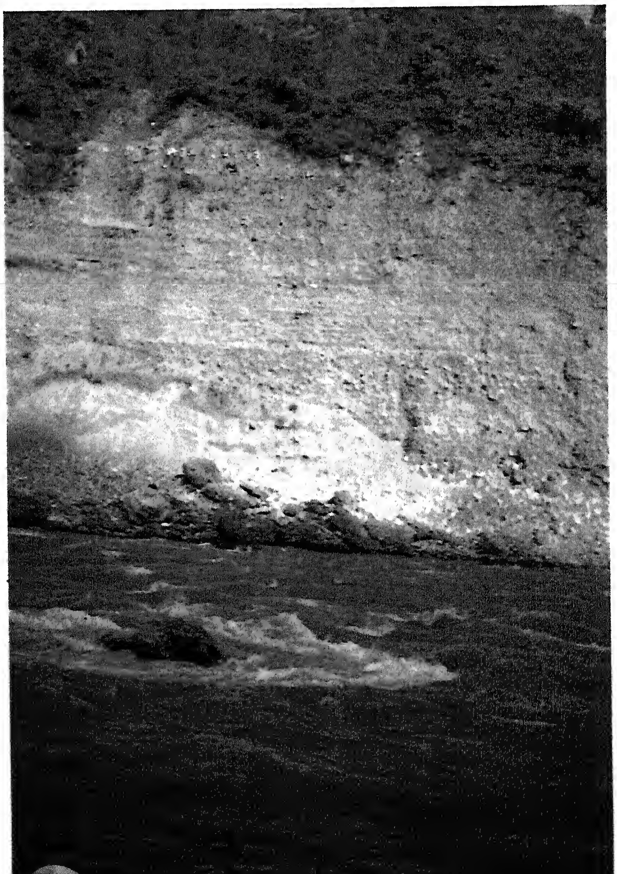


Plate 3.6 Riparian Slip And flow of unconsolidated terrace materials into the Alaknanda river.
Location: Dhari village, Srinagar-Rudraprayag section

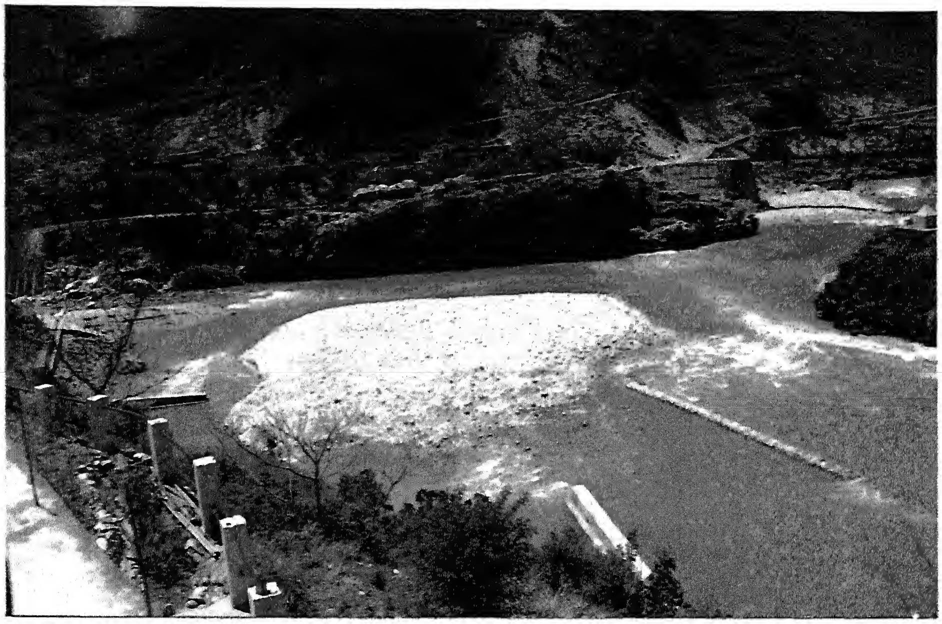


Plate 3.7 Pebble dyke and concrete walls built at Karnprayag to reduce bank erosion
Location: Karnprayag

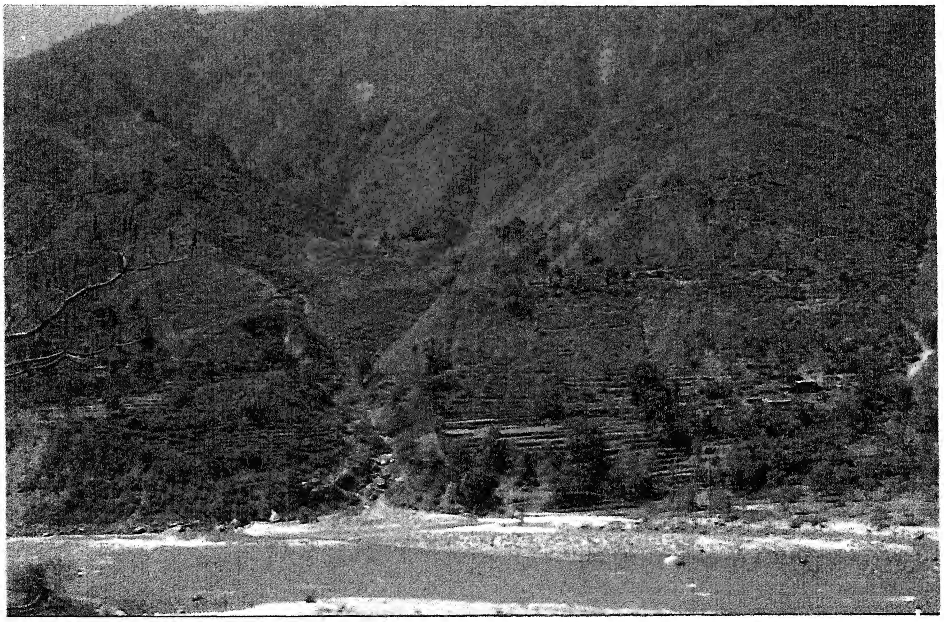


Plate 3.8 Steeply sloping gullies
Location: Rudraprayag–Karnprayag section

features, which essentially plays vital role in sediment production and supply into the Alaknanda river. As observed in the field, the erosion potential of the gully increases with increase in the slope of the catchment. The amount of sediment supply by the gullies is further enhanced due to presence of a landslide located at the mouth of these gullies or tributaries. Such a situation was observed at a location downstream of Kaliasaur landslide on the roadside (Plate 3.9). Many of the gullies have undergone so much of incision that they have developed into a major tributary to the Alaknanda river as shown in Plate 3.10. It first started off as a small gully, and then incised and widened into a tributary system. This is now actively eroding the slopes and terraces at both banks and is a major source of sediment supply to the Alaknanda river.

3.2.3 Alluvial Fans

Alluvial fans are deposit which are generally formed due to sudden fall of gradient of the river in the foothill region They are not very common geomorphological features in mountainous region. In the study area, small fans have formed at the confluence of the tributaries originating at high altitudes with the Alaknanda river at comparatively lower level. Most of the alluvial fans within the study area are composed of inhomogeneous mixture of coarser particles like gravels and pebbles with sandy as well as muddy materials as matrix. These fan range in size from a couple of meters to 10 meters or so in the Srinagar-Rudraprayag section (Plate 3.11) in contrast to the large-scale alluvial fans in Rudraprayag-Nandprayag section (Plate 3.12). The exceptionally large fan shown in Plate 3.12 has developed on the right bank of Alaknanda river about 2 kms downstream of Langrasu village. The size variation of alluvial fans may be related to the slope of the area. In Rudraprayag-Nandprayag section, high slopes, high rates of erosion and therefore availability of more sediment may have allowed large scale to develop. Many small to

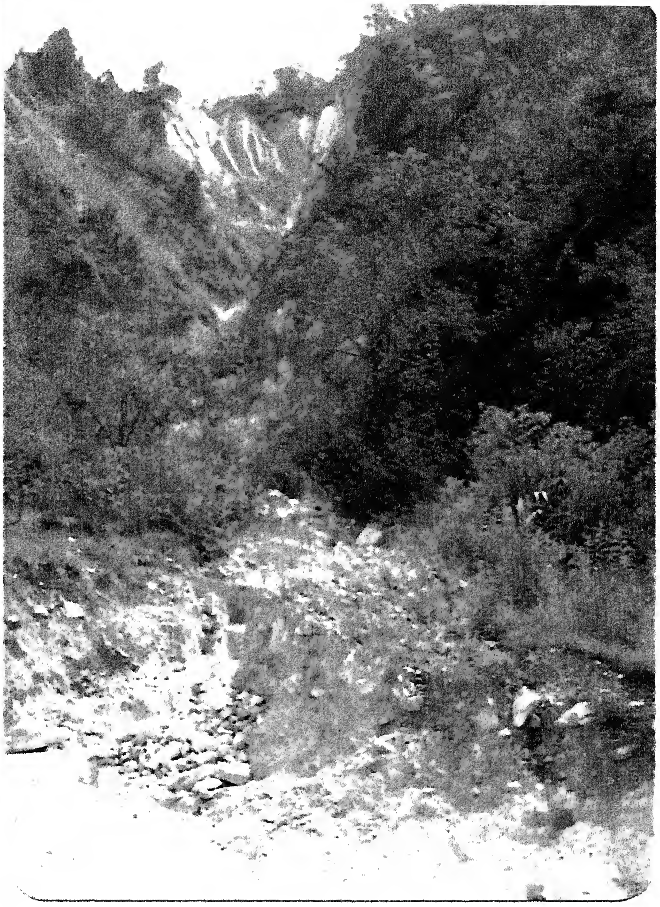


Plate 3.9 Landslide zone located at the source of the gully
Location: 100 meter upstream of Kailiasaur

Plate 3.10 Development of a gully into a tributary by terrace incision
Location: Nagrasu village, Rudraprayag-Karnprayag section

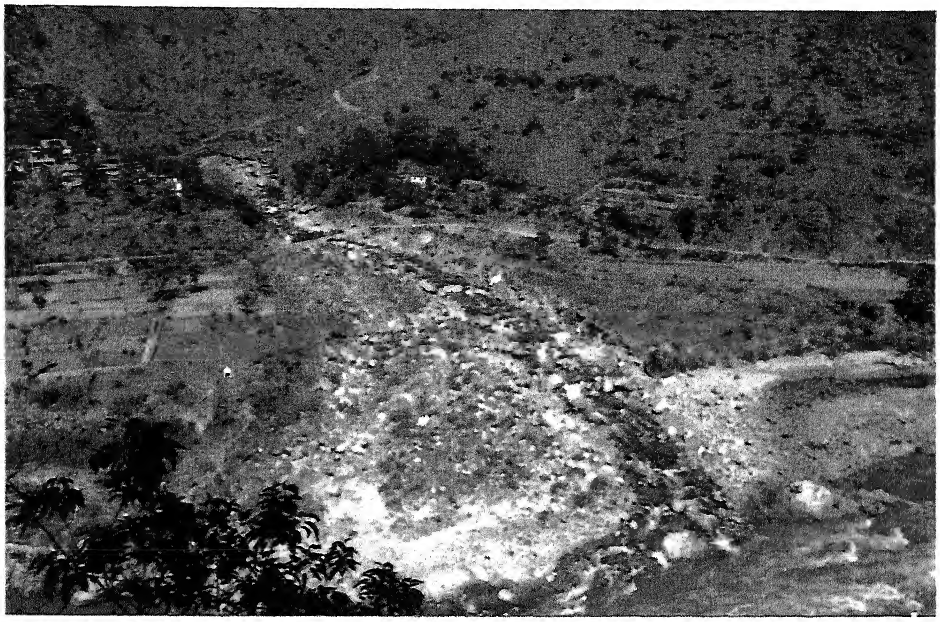


Plate 3.11 Small-scale alluvial fan formed at a tributary confluence of Alaknanda river (approximate size: 50m)
Location: Srinagar-Rudraprayag section

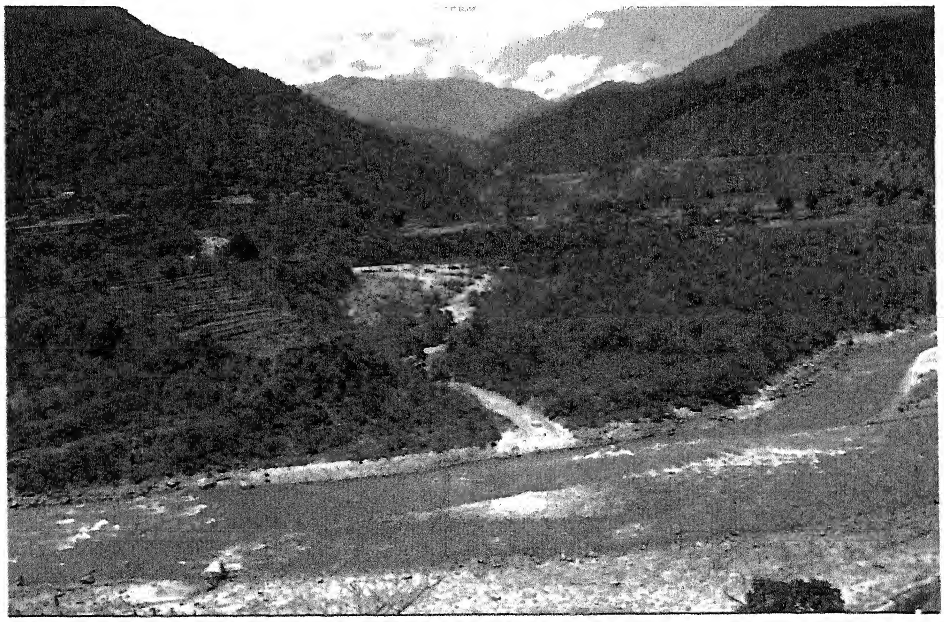


Plate 3.12 Large-scale alluvial fan formed at a tributary confluence of Alaknanda (approximate size half a kilometer)
Location: Langrasu village, Karnprayag-Nandprayag section

moderate-sized fans were also identified all through the area associated with the perennial Alaknanda river. The Alaknanda river reworks the inhomogeneous, unconsolidated deposits of these fans during the high flow season. These alluvial fans therefore contribute significant quantities of sediments to the river Alaknanda.

3.2.4 Channel Bars

Small-scale channel bars have developed at many locations in the relatively flat reaches of the Alaknanda river. At sharp bends, point bars and side bars (Plate 3.13) were also observed at concave banks at many locations. These bars generally consist of loose gravels, pebbles and sand, and act as the temporary sites of sediment accumulation. During high flow periods, the bars are eroded and moved downstream. These features are more important from the viewpoint of their use as indicators of zones of temporary sediment accumulation.

3.3 LANDSLIDE ZONES IN THE ALAKNANDA CATCHMENT

In general, the entire stretch of Alaknanda valley is full of landslide zones both at the right and left bank of the valley.

During the field investigation, it was observed that landslides are one of the most important zones where sediments are produced and then moved through gullies or are falling straight into the river waters (Plate 3.14). As discussed later, these zones were used as sites for validation of my erosion intensity model obtained through GIS analysis. The objective of this section is to describe some of landslide zone observed during field investigation and demonstrate them to be one of the important sediment supply zones.

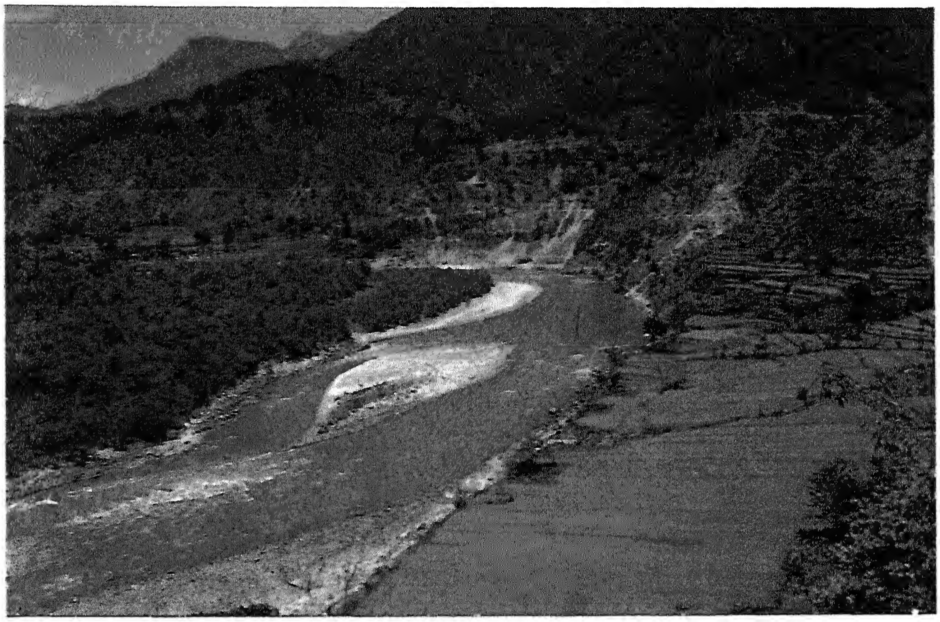


Plate 3.13 Point bar and side bars developed along river Alaknanda
Location: Langrasu village, Karnprayag-Nandprayag section

Sarkar (1996) prepared a landslide map of the Srinagar-Rudraprayag section. Firstly, the uncontrolled mosaic of aerial photographs was prepared to obtain a synoptic view of the area. Secondly, a detailed stereoscopic study, using Zoom-Stereosketch was

carried out. Finally, the information from photo-interpretation was transferred into the topographic map with the help of ground control points. The landslide map (Figure 3.1) shows spatial distribution of all the existing landslides of the area. Few landslides which are not very clear in aerial photographs have been marked in the map after field investigation. Overall 139 landslides were identified by Sarkar (1996) and marked in the landslide map. The map reveals higher concentration of landslides to the south of Alaknanda than to the north of it.

The most important and well known landslide in the study area is the Kaliasaur slide located on the left bank of river Alaknanda about 3 km upstream of Dhari. It damaged a road for a 100m stretch (Plate 3.15). This is one of the largest landslides in this region on the left bank of the Alaknanda River, on the Rishikesh-Badrinath road. The presence of fault zones, shear zones, extensive erosion by river/gullies, heavy precipitation in the highly jointed, fractured and pulverized rock mass, represent major causative factors of the sliding activity in this region. Many other significant landslides both active and dormant are also found to occur in Srinagar-Rudraprayag section along the Rishikesh-Badrinath road. Other forms of mass wasting like soil creep and debris fall are also common in this part of Garhwal Himalayas (Plate 3.16). These soil creeps could be easily identified as slowly moving unconsolidated soils and overburden. They are associated with typical bending of tree trunk along the movement direction. These soil creeps are very common features near Rudraprayag region.

Plate 3.14 Landslide acting as the sediment source to river Alaknanda
Location: Kaliasaur

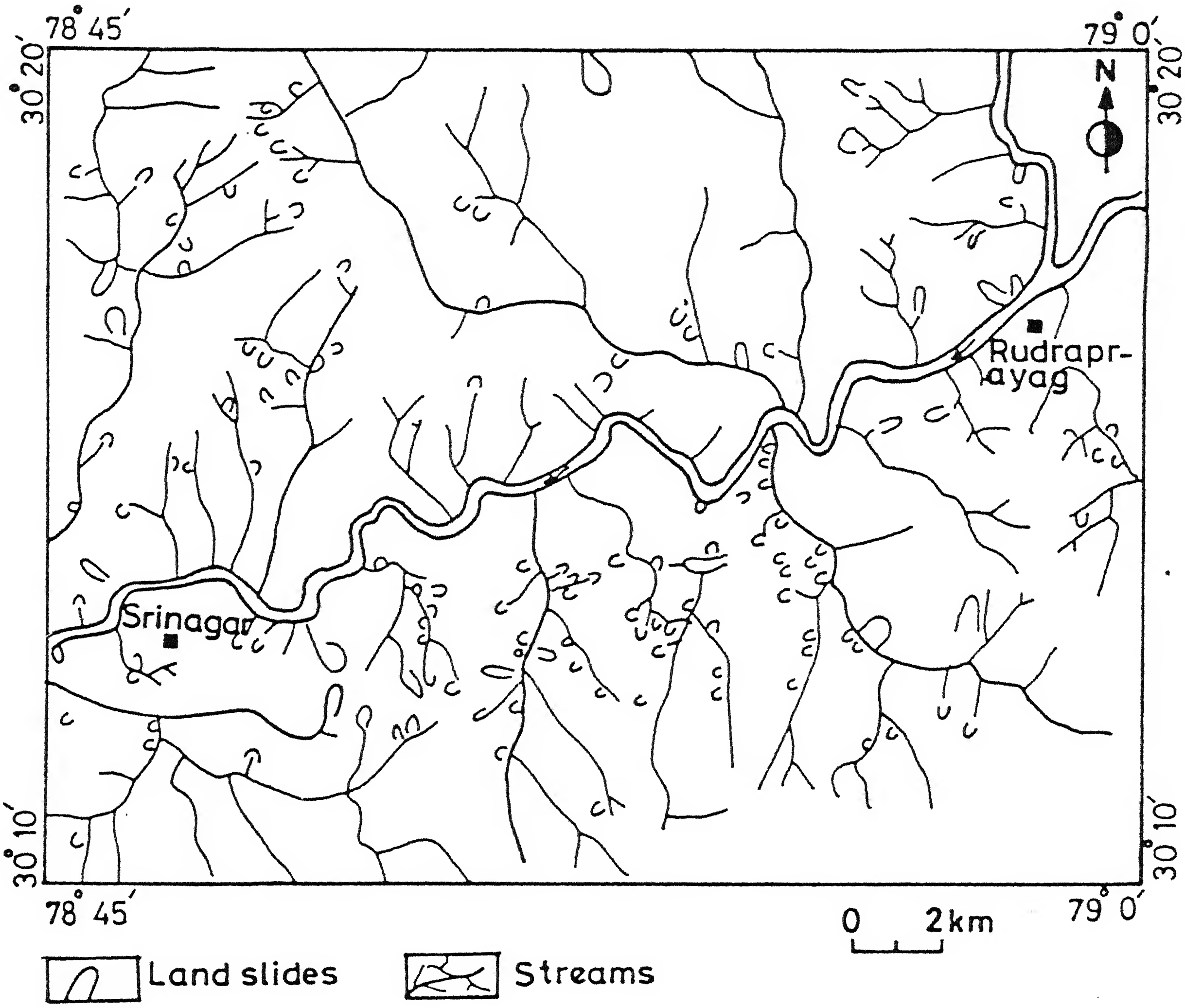


Figure 3.1 Landslide map of Srinagar-Rudraprayag section (after Sarkar, 1996)

Plate 3.15 Kaliasaur landslide; total extent of this slide is about 100 m along the roadside and is a major hazard in the region.

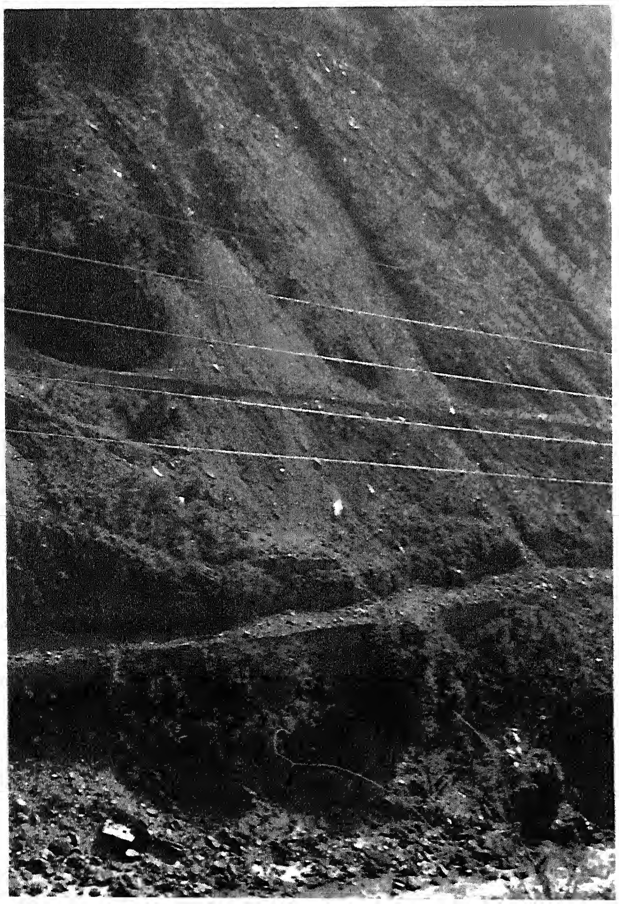


Plate 3.16 Debris avalanches on the right bank of river Alaknanda.
Location: 2 Km. Upstream of Srinagar

3.4 DISCUSSION

Field investigations along the river Alaknanda from the Srinagar-Rudraprayag section have helped to make a quantitative assessment of geologic and geomorphic features and processes from the view point of their erosion potential and sediment production. Broadly, two classes of sediments sources are identified, primary and secondary. This distinction is based on the following criteria:

(i) Primary sources are those with higher capacity of sediment supplying to the river compared to secondary sources. Primary sources generally include large-scale geomorphological features deposited in the geological past or any in-situ high sediment producing geomorphic features. In the study area, The features that are grouped under primary source are landslide zones, gully erosion, and terraces/riparian slip.

(ii) Secondary sources are small geomorphic features compared to primary sources. Generally, these geomorphic features are deposited in geological present by fluvial or glacio-fluvial action. Later, the river reworks them mainly in the high flow season thus generating small quantities of sediment. For the present study the alluvial fan, within channel bars, point bars and side bars are the features which are classified as secondary sediment source.

Moreover, field investigations also indicate that slope, lithology and structure play relatively more important role in sediment production. Among these, valley or catchment slope plays the most active role in sediment production in the study area. Field observations suggest that in the reaches of higher slopes sediment production is enhanced either in the form of debris-slides, landslides, gully erosion and formation of alluvial fan. Moreover, the discharge of most tributaries and streams flowing through this region

increases in reaches with high slopes as a result of which the erosion intensity also increases. The other controlling factors include drainage density, vegetation that have been assessed through analysis of topographic sheet and remote sensing data (to be discussed in Chapter 4). As shown later, the field observations served the basis for qualitative ranking of geologic and geomorphologic processes/features during GIS analysis.

Chapter 4

IMAGE PROCESSING FOR THE GENERATION OF THEMATIC LAYERS

4.1 GENERAL

Thematic maps for various factors controlling erosion and sediment production in the Alaknanda were prepared for the study area through digital remotely sensed data and available maps and field data. As mentioned in Chapter 3, these factors included slope, lithology, drainage density, structural and lineament intensity, geomorphology, and vegetation. The field information was used as the ground reference data for the classification of each of these factors arranged in the form of thematic layers. This chapter first describes various data products used for the study. This is followed by description of procedures required for the preparation database for estimating erosion potential of the area. This data base preparation is the most important aspect for any GIS-assisted application.

4.2 DATA PRODUCTS / SOFTWARE USED FOR THE PRESENT STUDY

Mainly two groups of data products were used. The first group consists of remotely sensed data from IRS-1B satellite. The second group includes various geological and topographic maps. Details of these data products are given in Table 4.1.

Table 4.1 Data products used for the study

Data type	Details	Remarks
Remotely sensed data		
IRS-1B LISS II	Path \ Row: 28 – 46 B2 Path \ Row: 28 – 46 A2	Area: Rudraprayag to Karnprayag Area: Srinagar to Rudraprayag
Maps		
Regional lithological and structural Map	Scale: 1.5 cm = 5km	Valdiya (1980)
Detailed Structural Map	Scale: Not Available	Prasad and Rawat (1986) Area: Srinagar to Rudraprayag
Topographic sheet	Scale: 1: 250,000 (No.: NH 44-5)	Army Map Service, Corps of Engineers, US Army, Washington
Topographic sheet	Scale: 1 inch = 2 mile (No.: 53 N/SW, 53 J/SE)	Survey of India, 1946
Slope Map	Scale: 1 cm = 2 Km	Sarkar (1996) Area: Srinagar to Rudraprayag
Software		
IDRISI	Version: 2.0	Clark Laboratory, USA

It can be observed from Table 4.1 that the scale and resolution of the maps available for the two sections along the river Alaknanda namely, Srinagar to Rudraprayag and Rudraprayag to Nandprayag are different. For the Srinagar-Rudraprayag section the available data is on larger scale whereas for the Rudraprayag-Nandprayag section the data is on smaller scale. Therefore, these two sections have been analyzed separately. The following section describes various steps involved in conversion of aforementioned data products into suitable thematic maps. In the next chapter these maps will be used for identifying erosion prone areas in the Alaknanda catchment.

4.3 GENERAL IMAGE PROCESSING

Computer based digital image processing (DIP) mainly includes three operations: pre-processing, enhancement, and pattern recognition. Pre-processing refers to initial processing of raw data to calibrate image radiometry, correct

geometric distortions and remove noise. The nature of the particular pre-processing required depends upon sensor's characteristics because pre-processing is designed to remove any undesirable image characteristics produced by the sensor. The corrected images are then subjected to enhancement and/or classification. Enhancement produces a new, enhanced image that is displayed on CRT for visual interpretation. This enhanced image may be easier to interpret than the original image in many ways. Pattern recognition attempts to replace visual interpretation step with quantitative decision making. The output from this is in the form of thematic map in which each pixel in original image has been classified into one of several themes.

4.3.1 Image pre-processing

The operation involves correction of distorted or degraded image to create a more faithful representation of the original scene. Initially the raw image data is processed to correct the geometrical distortions and then calibrate the data radiometrically and eliminate the noise present in the data. The standard remotely sensed data products were acquired from NRSA, Hyderabad, which were already corrected for any radiometric and geometric errors. Therefore, no geometric or radiometric correction was applied for the present study.

4.3.2. Image enhancement

The image enhancement is applied to the raw image data in order to more effectively display or record the data for more subsequent visual interpretation. Normally, the image enhancement procedures involve techniques, which increases the visual distinction between the features present in the scene. Mainly five types of enhancement operations, contrast stretching, low pass filtering, edge enhancement, ratioing, and generation of FCC (Plate 4.1) were used.

4.3.3 Pattern recognition

Pattern recognition principles were applied to classify various remotely sensed images by using spectral features in order to prepare two thematic maps i.e. vegetation and geomorphic maps.

4.4 PREPARATION OF THEMATIC MAPS

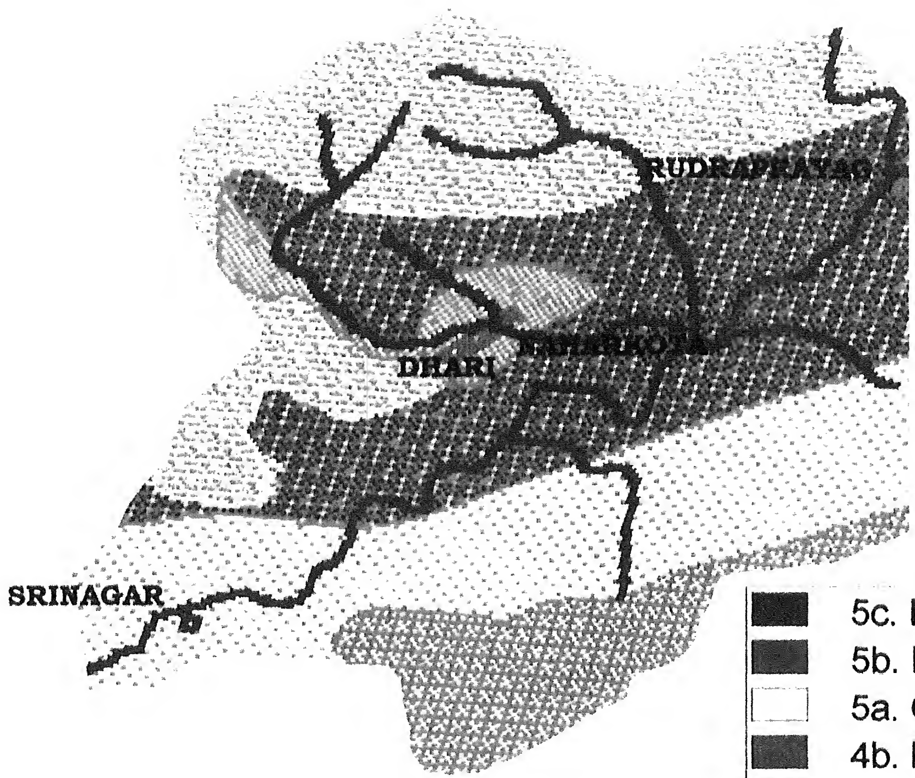
This section describes the specific image processing steps carried out for the generation of thematic maps containing various factors controlling erosion in the Alaknanda catchment.

4.4.1 Lithological Map

A regional scale lithological map at scale 1.5cm = 5 kms (Valdiya, 1980) of the study area catchment was scanned on UMAX flatbed scanner (Astra 1200S) using a dpi value of 600. This scanned image was subsequently resampled with the help of 10 ground control points to register the data on the grid system of the base map. For spatial interpolation, the second polynomial was used whereas for the intensity interpolation the bilinear algorithm was used. The registered lithological maps of two different sections, comprising of different litho-stratigraphic units, were vectorised. During vectorisation, each unit that corresponds to a vector polygon was given a unique feature identification code. These vectorised polygons were then rasterized to produce a classified lithological image of the study area catchment (Plates 4.2 and 4.3) and corresponds to the litho-stratigraphic classification given in the Table 2.2.

Plate 4.1 FCC 432 of the Alaknanda Catchment: Srinagar-Nandprayag

Lithological Map: Srinagar to Rudraprayag Section



MassGIS

- 5c. Nagthat - Berinag Fm.
- 5b. Nagthat - Berinag Fm.
- 5a. Chandpur Fm.
- 4b. Mandhali (Sor + Thalkedar) Fm.
- 4a. Deoban (Gangolihat) Fm.
- 3b. Rautgara Fm.
- 3a. Chakrata Fm.
- 2b. Deboguru Porphyroid
- 2a. Bhatwari & Barkot unit.
- 1c. Granite - Granodiorite and Augen Gneiss
- 1b. Granite - Granodiorite and Augen Gneiss
- 1a. Saryu - Gumalikhet and Munsiari Fm.
- 1. Almora Gp. 2. Ramgarh Gp. 3. Damatha Gp

Meters

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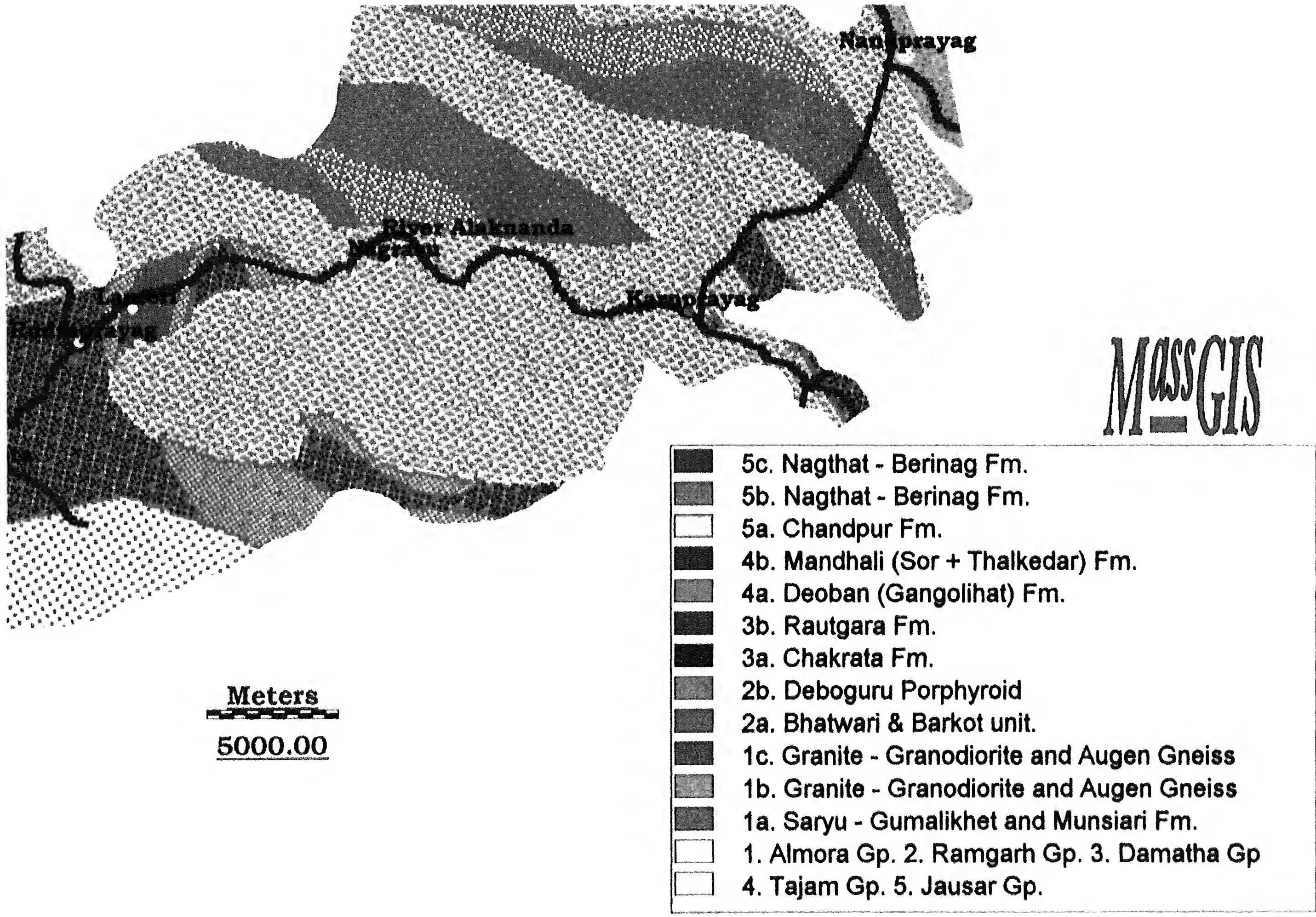
Plate 4.2

Plate 4.3 Lithological Map: Rudraprayag-Nandprayag section



The lithological classes were ranked as given in column 3 of Table 4.2. These ranking are based on the susceptibility of litho-stratigraphic unit to erosion, which depends on the hardness and compactness characteristics of the associated rock types. The higher the ranking, the higher is the chance of the lithology to erode. Similar types of lithology are given similar ranking.

Table 4.2 Ranking of the lithological classes: Srinagar-Nandprayag section

Group	Formation	Ranking
Almora	Granite-Granodiorite Augen Gneiss	9
	Saryu Fm	8
Ramgarh	Nathukhan	3
	Debguru porphyroid	8
Jausar	Naghthat – Beringnag Fm.	6
	Chandpur Fm.	5
Tejam	Mandhali Fm.	4
	Deoban Fm.	7
Damatha	Rauthgara Fm.	2
	Chakrata Fm.	1

4.4.2 Drainage density map

A drainage map of the Alaknanda catchment was prepared from a 1: 126250 scale topographic sheet (Plate 4.4). For computation of drainage density, the catchment was divided into equal area grid size of 22.5 sq. miles. The grid numbers are shown in Figure 4.1. Drainage length was measured for channels of all orders within each grid with the help of a chartometer. Planimeter was used for measuring area of the portions of the catchment not covered by a regular grid. The drainage density within each grid was calculated by the following formula:

$$Drainage\ density\ (DD) = \frac{Length\ of\ the\ stream\ carried\ out\ through\ all\ orders\ in\ a\ grid}{Area\ of\ the\ catchment\ within\ each\ grid} = \frac{TL_u}{A}$$

Plate4.4 Drainage map of Alaknanda Catchment: Srinagar-Nandprayag

Idrisi

The drainage density values for various grid numbers as shown in Figure 4.1 are listed in Table 4.3.

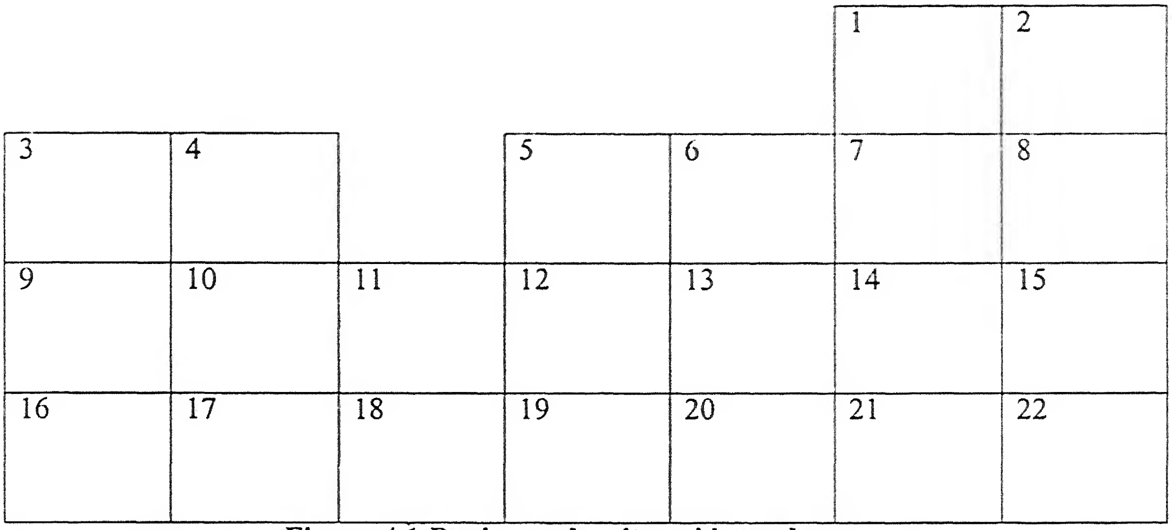


Figure 4.1 Drainage density grid numbers

Table 4.3 Grid-wise Drainage Density of the Alaknanda Catchment: Srinagar-Nandprayag section

Grid No.	TL_u (miles)	A (miles)	DD (per miles)
1	40.4	14.4	2.80
2	0.2	0.08	2.5
3	8.0	2.24	3.57
4	17.0	6.00	2.83
5	8.0	4.24	1.89
6	31.0	13.2	2.35
7	74.0	26.24	2.78
8	20.0	4.00	5.00
9	38.0	13.12	2.90
10	63.0	28.00	2.25
11	81.4	26.80	3.04
12	71.4	27.84	2.56
13	83.0	28.00	3.61
14	81.00	27.92	2.90
15	60.4	23.76	2.54
16	38.4	12.48	3.08
17	62.2	24.08	2.58
18	51.8	16.40	3.16
19	57.2	10.96	5.22
20	32.5	16.40	1.98
21	10.9	5.84	1.87
22	3.20	0.80	4.0

The drainage density values of 22 grids are ranging from 1.87 to 5.22. The distribution of the drainage density values is shown in Figure 4.2. These values were divided into 4 classes such that the range for each class is within ($\mu \pm 3\sigma$), where μ and σ are class mean and standard deviation respectively (Table 4.4).

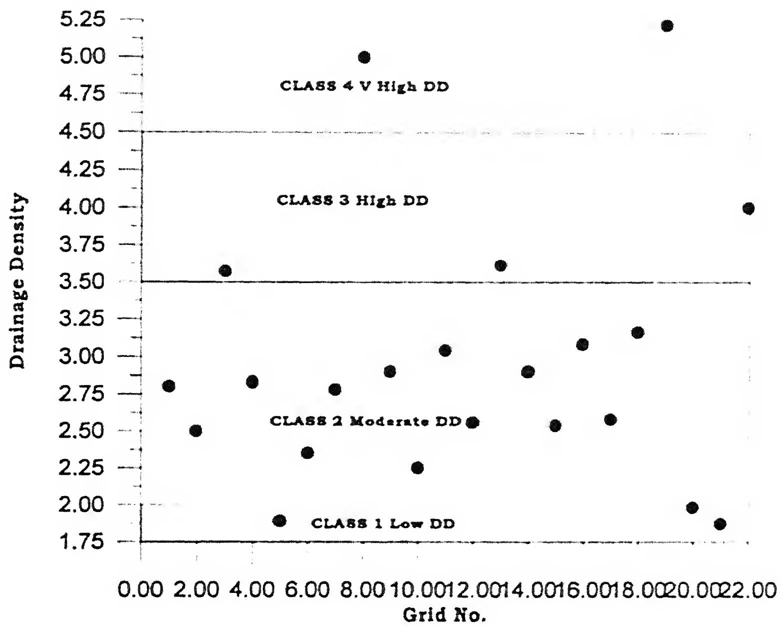


Figure 4.2 Gridwise drainage density distribution of Alaknanda catchment

Table 4.4 Drainage density classes

DD	Category	Class
1.00/mile - 2.00/mile	Low DD	4
2.00/mile - 3.5/mile	Moderate DD	3
3.5/mile - 4.5/mile	High DD	2
> 4.5/mile	Very high DD	1

The drainage map was then scanned and the grids were digitized. These polygon vector grids were rasterized and each grid was assigned the corresponding class value. After this the drainage density map was resampled with the help of ground control points and was registered on the corresponding satellite image by following a similar procedure as in case of litho-stratigraphic map. Plates 4.5 and 4.6

Drainage Density from Srinagar to Rudraprayag

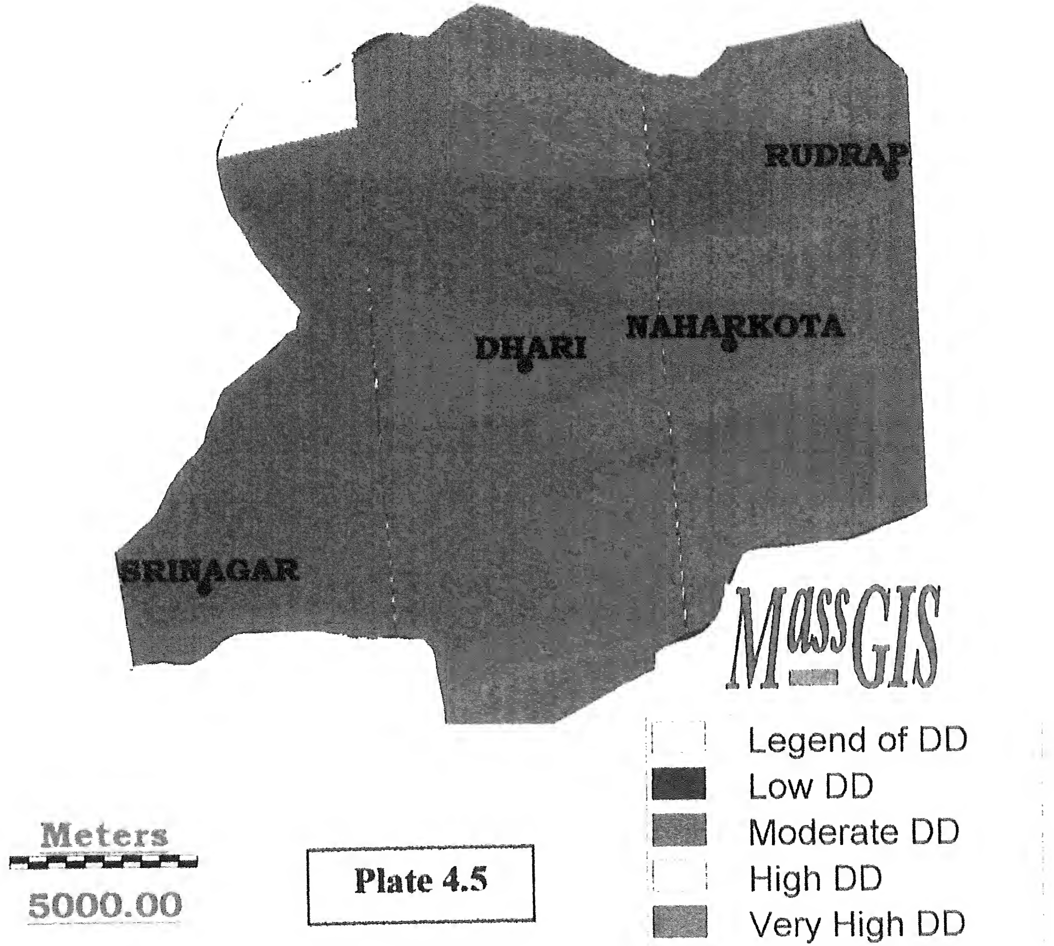


Plate 4.5

Drainage Density Map: Rudraprayag to Nandprayag

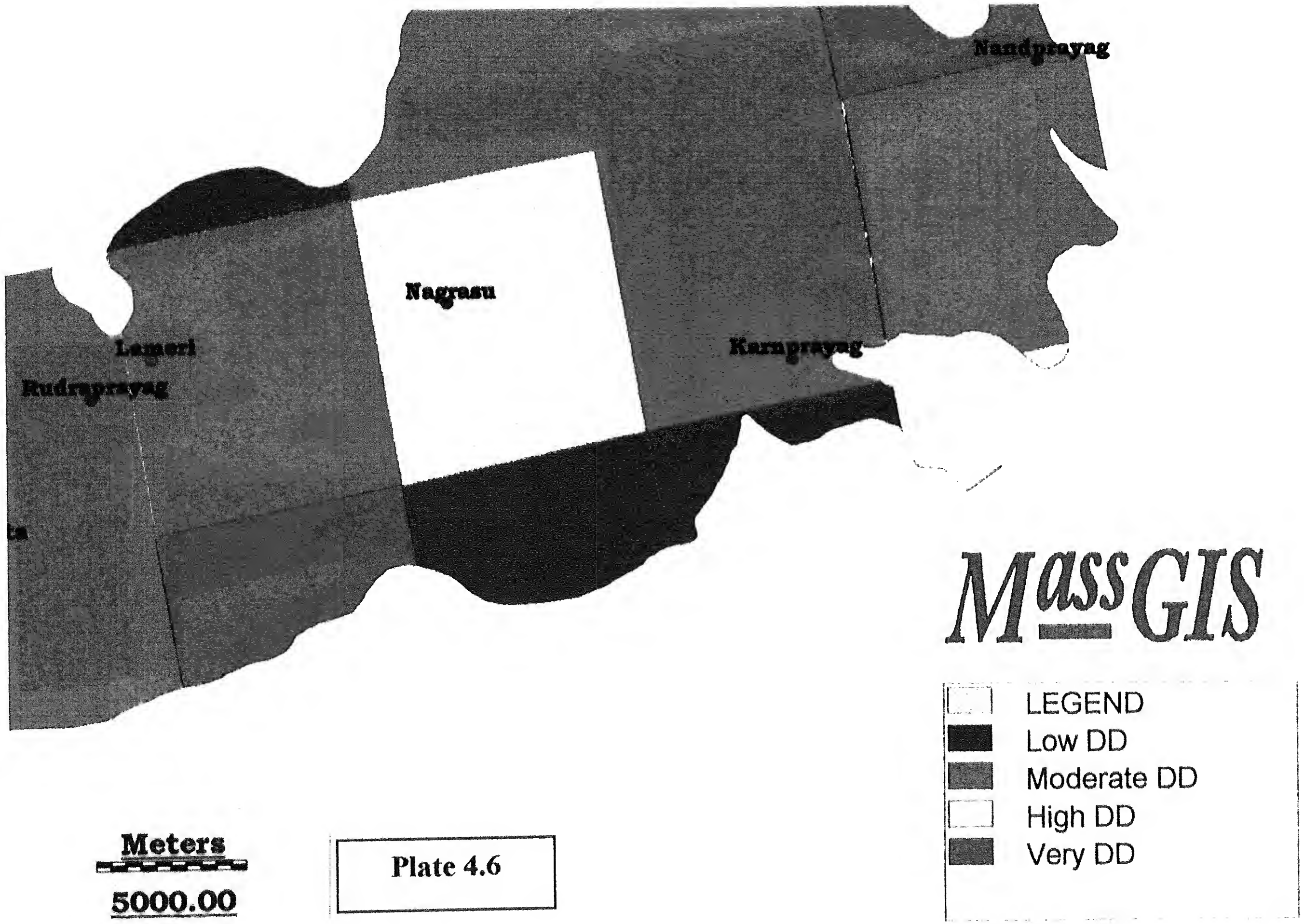


Plate 4.6

show the resampled drainage density maps for the Srinagar-Rudraprayag and Rudraprayag-Nandprayag sections respectively.

4.4.3 Geomorphological map

In the study catchment, various geomorphological features have formed in the recent past by different fluvial or glacial processes. Hence, these deposits are mostly unconsolidated or loosely compacted and act as potential sediment source. A geomorphological map of the study area was prepared from the remote sensing image through following steps:

(a) Different geomorphic features identified and located in the field as potential sediment source as mentioned in Chapter 3 were delineated on the satellite image. These features are valley, terrace, channel bar, alluvial fan, and gully.

The alluvial fan like deposits, mainly found in the Rudraprayag-Karnprayag section, are fairly large in size (Plate 3.12). Such deposits are not so abundant in the Srinagar-Rudraprayag section and are very small in size. So in the Srinagar-Rudraprayag section such features cannot be identified in the image. Therefore, the feature alluvial fan is missing in this section.

(b) Signature files were made for each of these geomorphic features by digitizing pixels containing these features at one or two known locations in the image. In Srinagar- Rudraprayag section where no alluvial fans were identified, four signature files were created. For Rudraprayag-Nandprayag section, all five signature files of the geomorphic features were prepared.

(c) Then after making signature file, which basically contains ground truth,

supervised classification was carried out in both of these sections using Gaussian maximum likelihood classification (GMLC) method. The GMLC classifies an image based on the information contained in a series of signature files and produces a classified image of the geomorphic structures in each section (Plates 4.7 and 4.8).

(d) Then training area accuracy analysis was carried between the reference and classified images. The percentage accuracy values for the Rudraprayag-Nandprayag section are presented in Table 4.5.

Table 4.5: Accuracy analysis of ground data & classified geomorphologic map

Category	% Accuracy
Valley	100
Terrace	99.40
Channel bar	100
Alluvial fan	97.00
Gully	100
Overall accuracy %	*96.30*

4.4.4 Vegetation Map

The procedure for the preparation of the vegetation map is similar to that of the geomorphic map. First, a NDVI map was prepared with the help of the following formula:

$$NDVI = (band3 - band\ 4) / (band3 + band4)$$

The NDVI values vary from –1 to +1. Any highly vegetated or forested region normally shows the NDVI value more than 0.5 while the bare rocks and the fresh sand generally have negative NDVI value. Based on NDVI image, topographic maps of the area and field observations, five categories of vegetation were identified with respect

Geomorphological Map: Srinagar to Rudraprayag Section

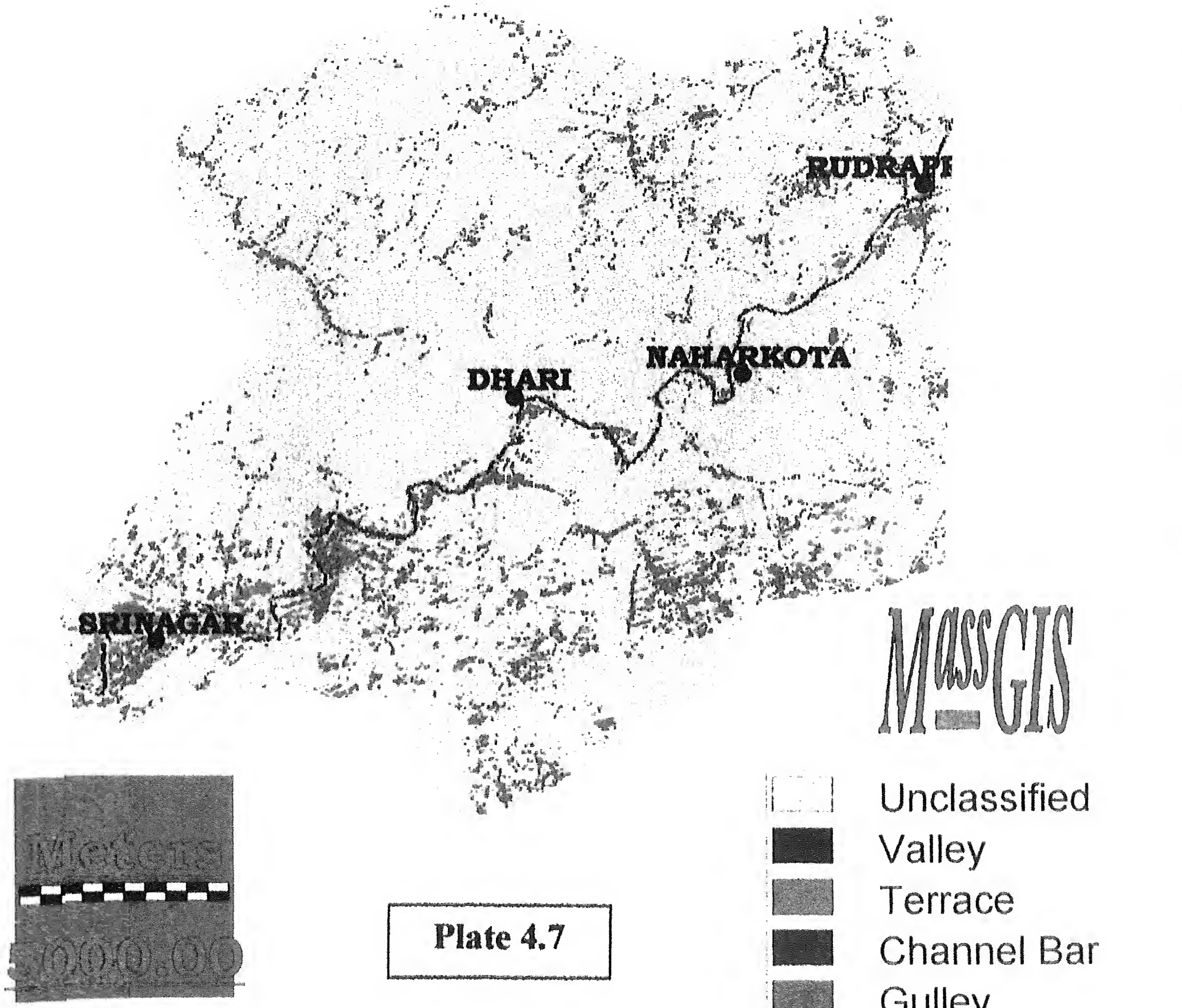
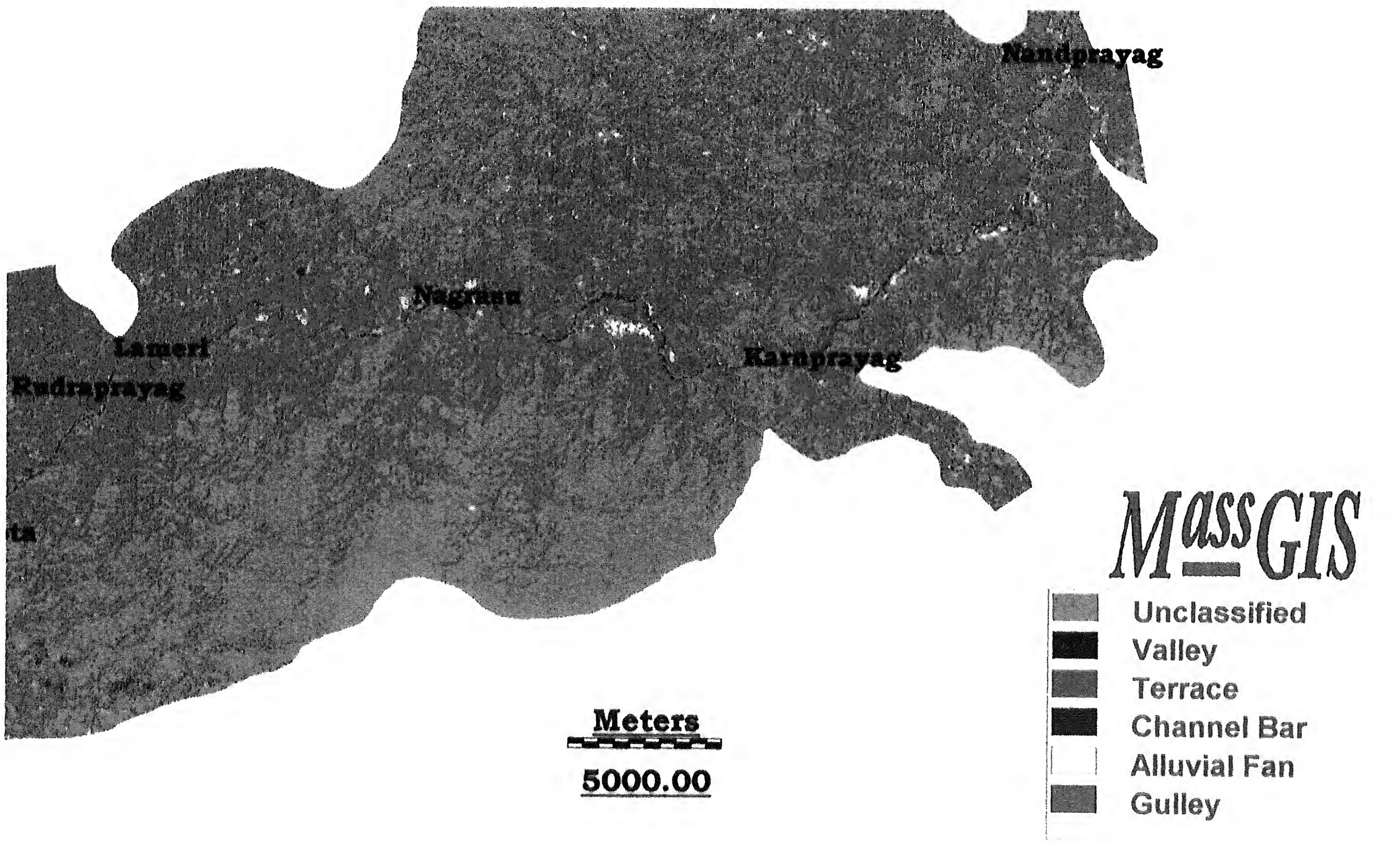


Plate 4.7

Plate 4.8 Geomorphological Map: Rudraprayag-Nandprayag Section



Classified Vegetation Map: Srinagar - Rudraprayag Section

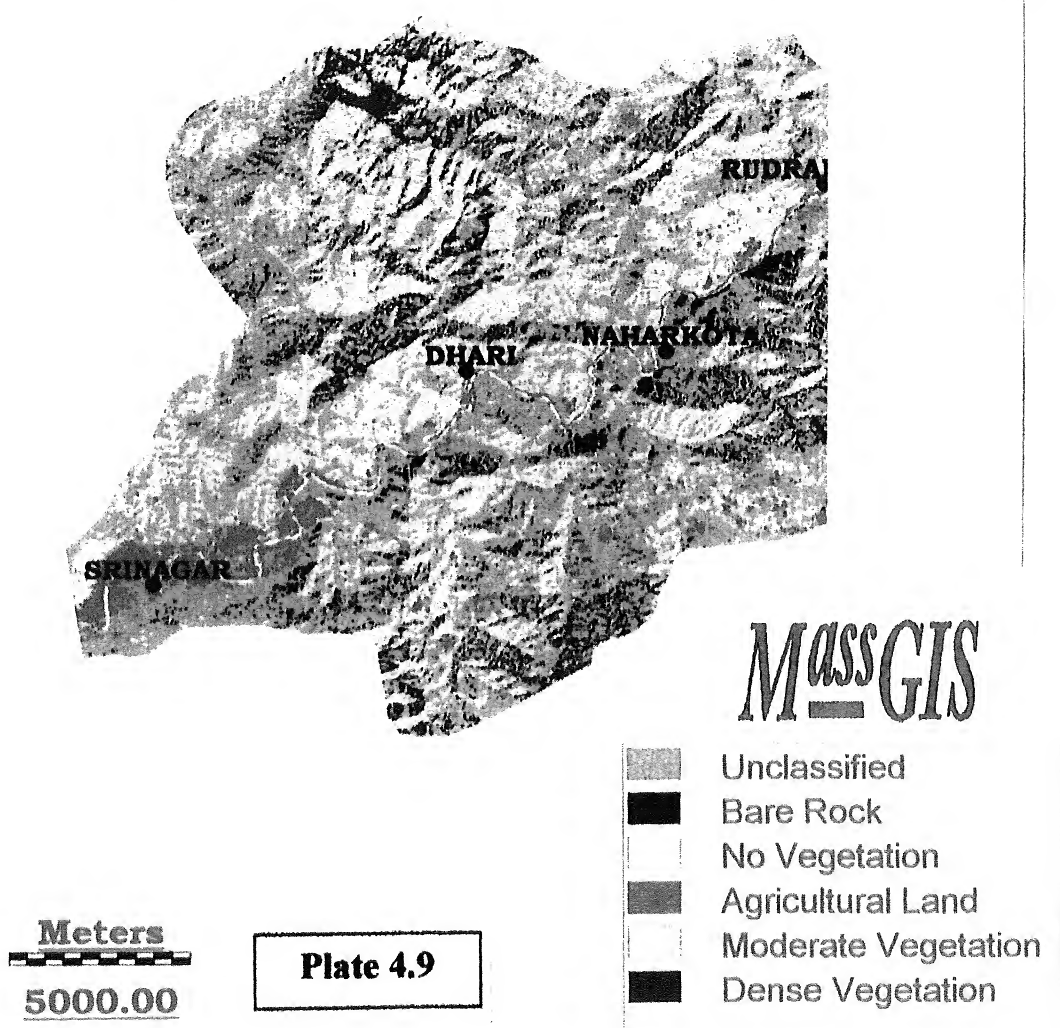
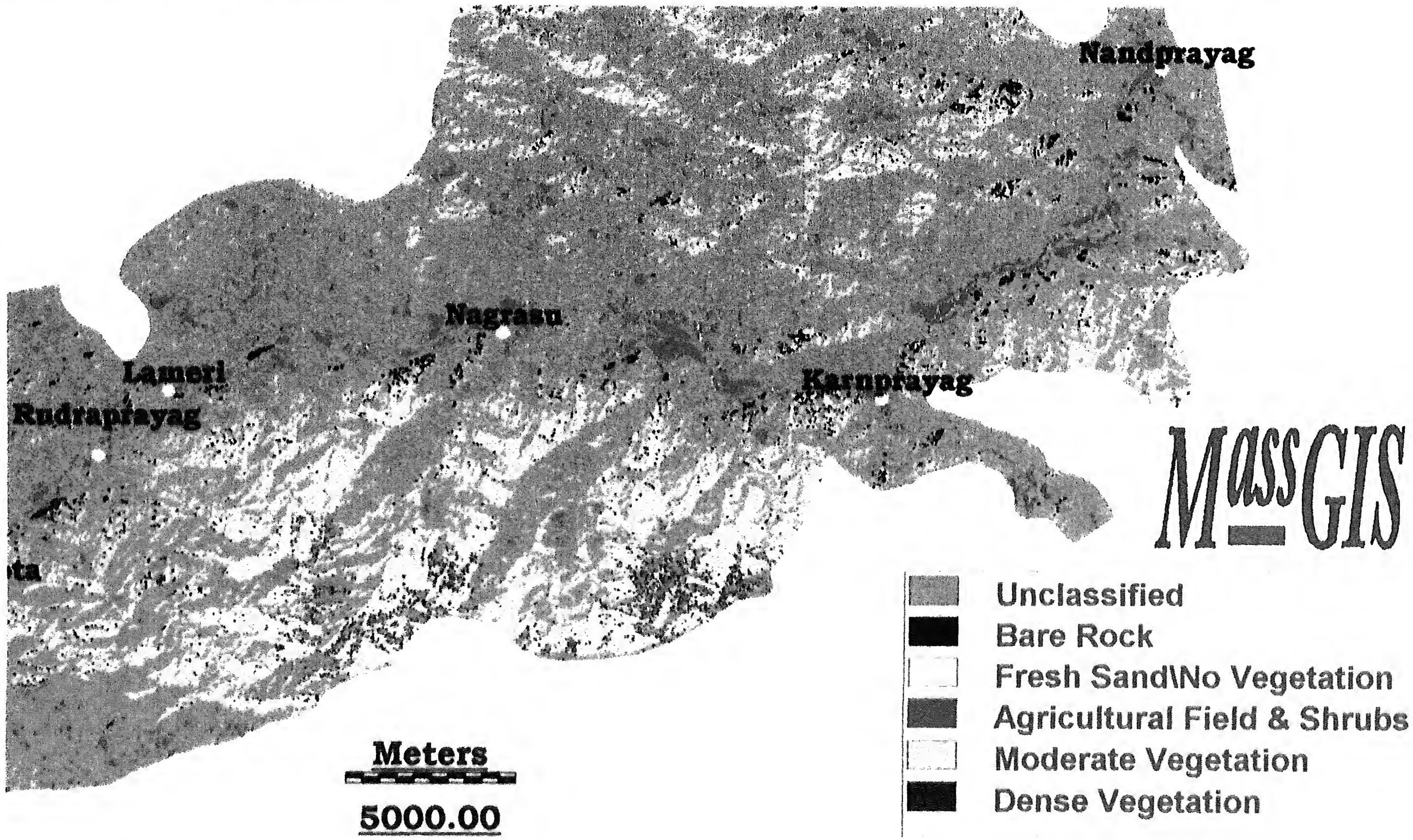


Plate 4.9

Plate 4.10 Vegetation Map: Rudraprayag-Nandprayag Section



most of the study area as seen in this plate. Only few areas have dense forest and bare rocks. For training pixels, the percentage accuracy for the overall classification as well as for all classes for Rudraprayag-Nandprayag section were observed to be 100%.

4.4.5 **Structural and lineament density map**

Fault, thrust and lineaments are features, which result in shattering of the rocks or create a blocky nature in rocks depending on the scale of analysis. Hence, they enhance erosion and act as a potential sediment source. The degree of erosion due to such features obviously depends upon the scale/resolution of the structural and lineament intensity map. A lineament and structural density map of the catchment was prepared to identify the high lineament density zone and hence locate the potential sediment production areas in the study catchment.

For the Srinanagar-Rudraprayag section, detailed structural map prepared by Prasad and Rawat (1986) was used to prepare the structural and lineament density map. On the contrary, for Rudraprayag-Karnprayag section a regional scale structural map of Valdiya (1986) was used, along with the lineaments extracted from remote sensing data.

The geomorphic lineaments, mainly the ridges and gullies, were extracted from the image by using sobel edge detector, which is generally used to identify features and areas of abrupt changes. The output sobel edge image was thresholded to produce prominent geomorphic edges. This thresholded image was subsequently screen-digitized.

The structural maps of both sections were then registered by resampling with

the grid system of the base images of corresponding section. The structural features of both the sections were then digitized. After this, the structural features of the Srinagar-Rudraprayag section were rasterised (Plate 4.11). In the Rudraprayag-Nandprayag section, both the structural as well as the lineament data were merged by rasterising both the lineaments and structural features on a single image (Plate 4.12).

The final images (Plates 4.11 and 4.12) were then divided into grids to evaluate the lineament density in each of these grids. The lineament density within each grid is determined by the formula:

$$Lineament\ density\ (LD) = \frac{Length\ of\ the\ lineament\ within\ each\ grid}{Area\ of\ each\ grid} = \frac{TL_d}{A}$$

The distribution of the lineament density values as shown in figures 4.3 and 4.4 correspond to Srinagar-Rudraprayag and Rudraprayag-Nandprayag respectively as shown in the Tables 4.6 and 4.7. These lineament density values of section were then divided into sub-classes as shown in Tables 4.8 and 4.9. The basis of this classification is purely statistical. Each of the sub-class values of the lineament density range within ($\mu \pm 3\sigma$) where μ and σ are the mean and standard deviation of the lineament density values in that class. A plot of lineament density values also facilitated the class arrangement. The final lineament density map (Plates 4.13 and 4.14) was then re-classified on the basis of the sub-classes as given in Tables 4.8 and 4.9.

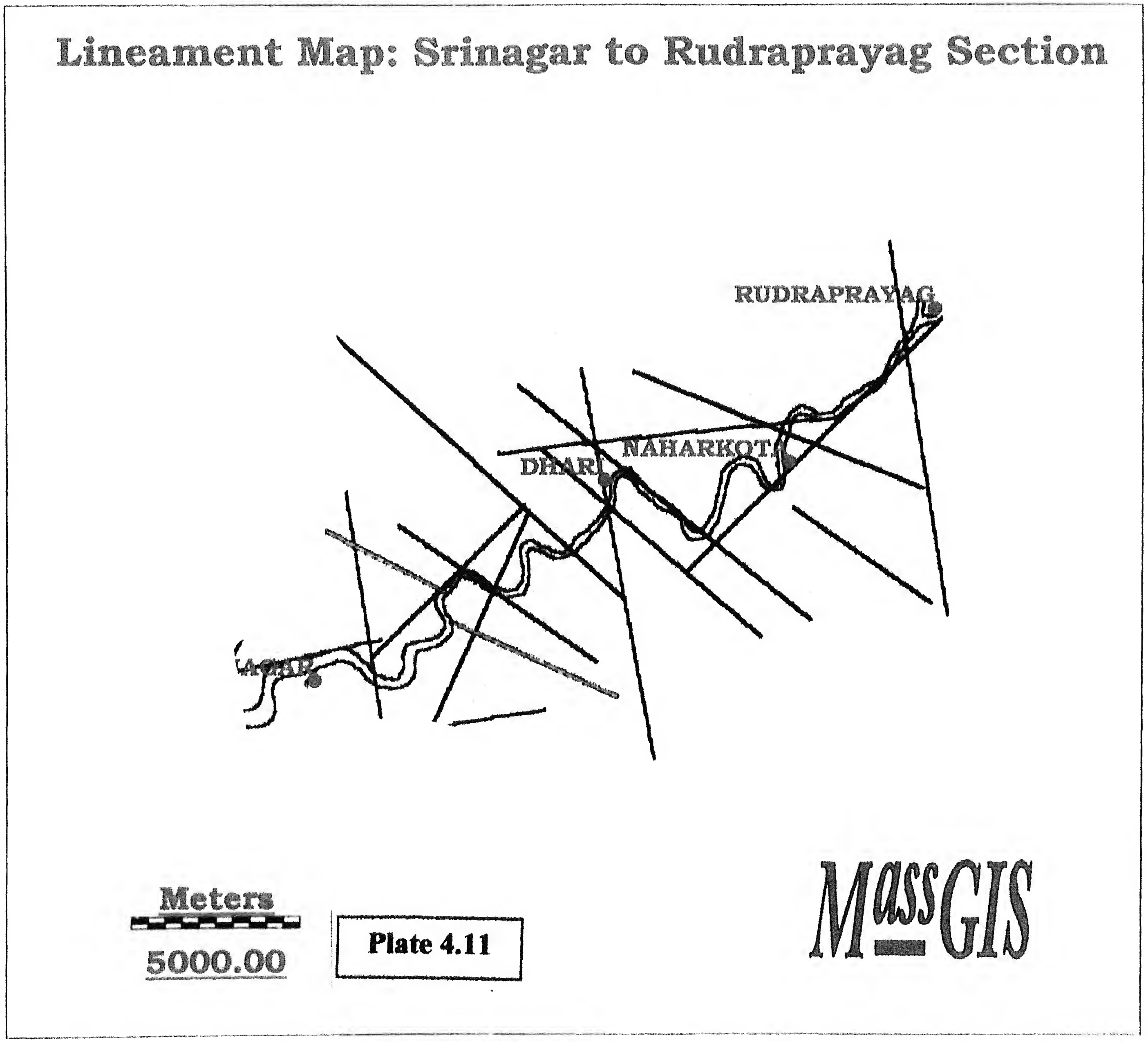

Lineament Map: Srinagar to Rudraprayag Section
RUDRAPRAYAG
NAHARKOTA
DHARI
Meters
5000.00
MassGIS

Plate 4.11

Plate 4.12 Structural and Lineament Map: Rudraprayag-Nandprayag

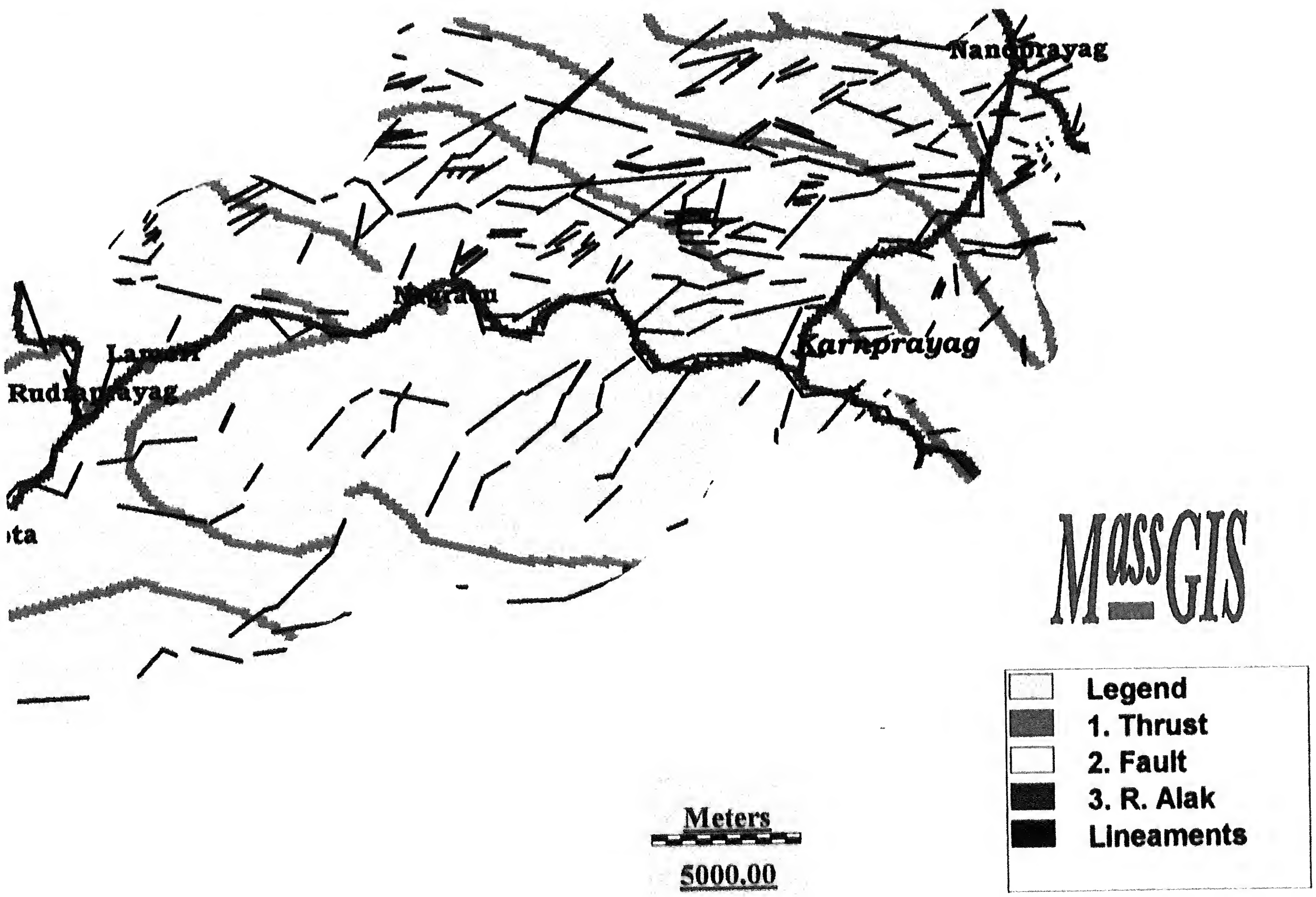
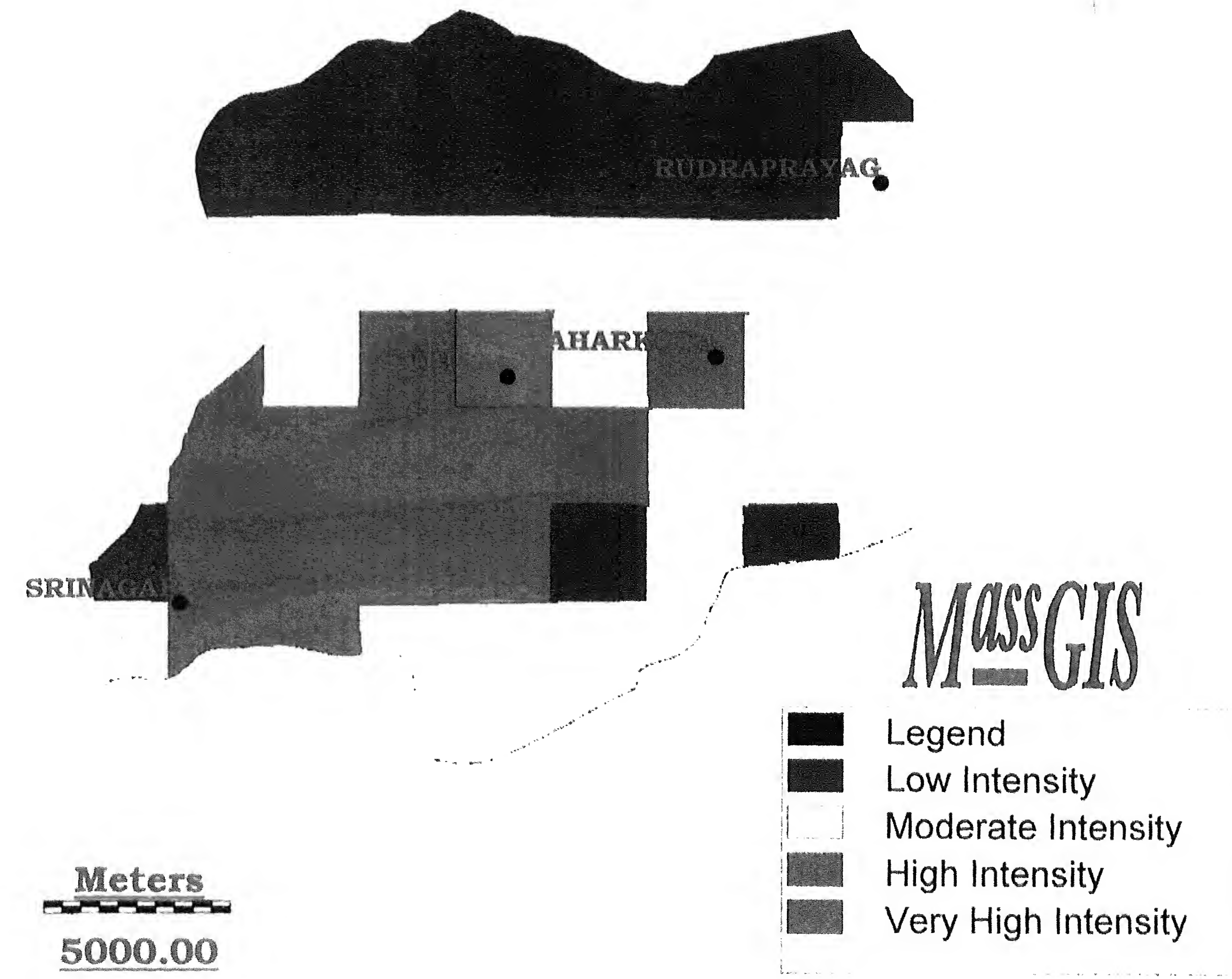


Plate 4.13 Lineament Density Map: Srinagar-Rudraprayag Section



Lineament Density map: Rudraprayag to Nandprayag Section

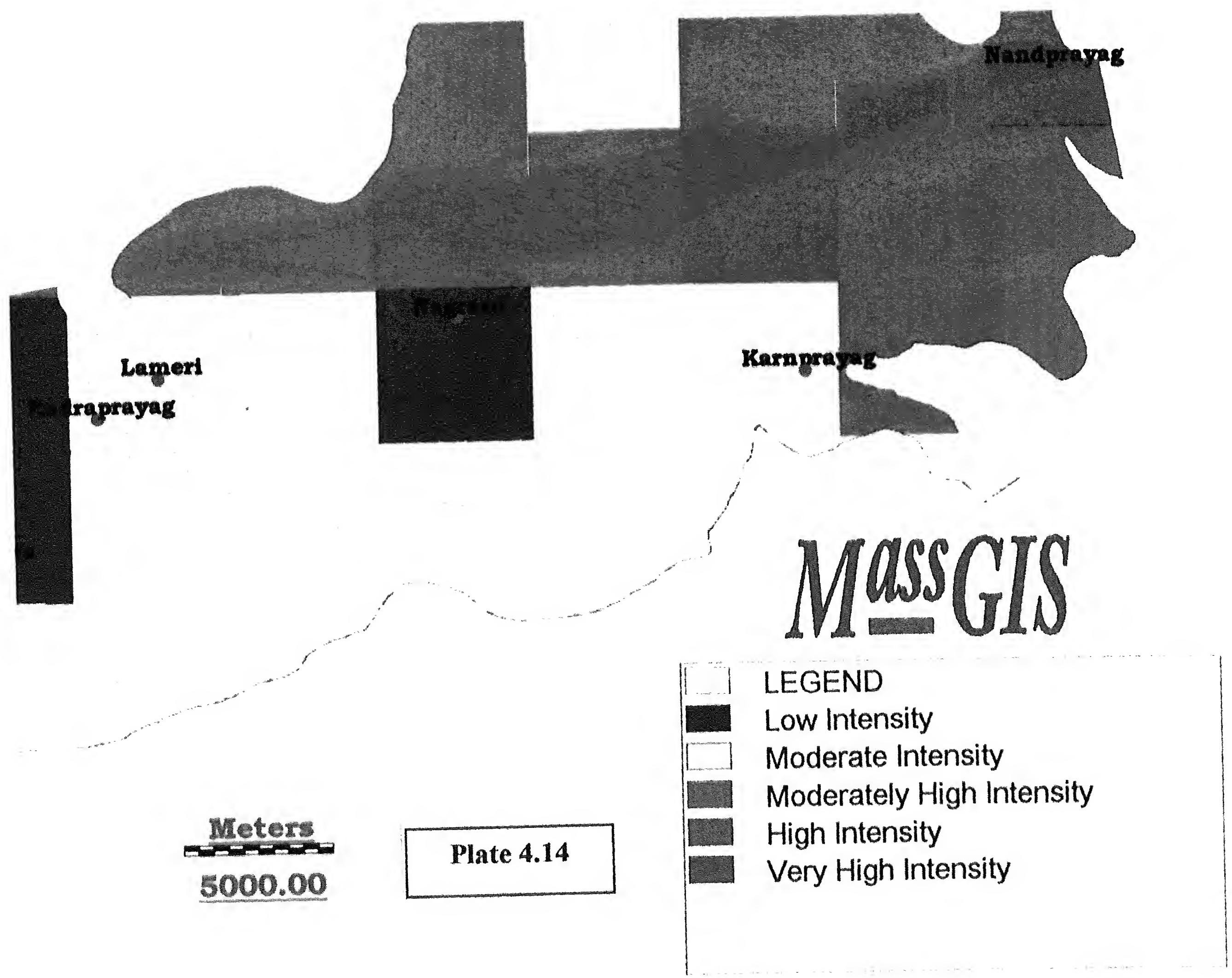


Plate 4.14

Table 4.6 Grid-wise lineament density of the Alaknanda catchment:

Srinagar-Rudraprayag section

								1 LD=0.087	
		2 LD=0.175						3 LD=0.175	4 LD=0.3125
		5 LD=0.75	6 LD=0.35	7 LD=0.3125	8 LD=0.475	9 LD=0.55	10 LD=0.50	11 LD=0.7125	12 LD=0.70
	13 LD=0.1125	14 LD=0.925	15 LD=0.34	16 LD=0.975	17 LD=2.025	18 LD=0.71	19 LD=1.06	20 LD=0.725	21 LD=0.675
	22 LD=0.55	23 LD=0.96	24 LD=1.09	38 LD=1.09	39 LD=1.34	40 LD=1.25	41 LD=1.3	42 LD=0.70	44 LD=0.625
45 LD=0.26	46 LD=1.075	47 LD=1.09	48 LD=0.08	49 LD=1.29	50 LD=0.92	51 LD=0.525	52 LD=0.275		
53 LD=1.37	54 LD=0.525	55 LD=1.00	56 LD=1.05	57 LD=0.425	58 LD=0.30	59 LD=0.20			
60 LD=0.93	61 LD=0.97	62 LD=0.43	63 LD=0.77						

LD - Lineament density

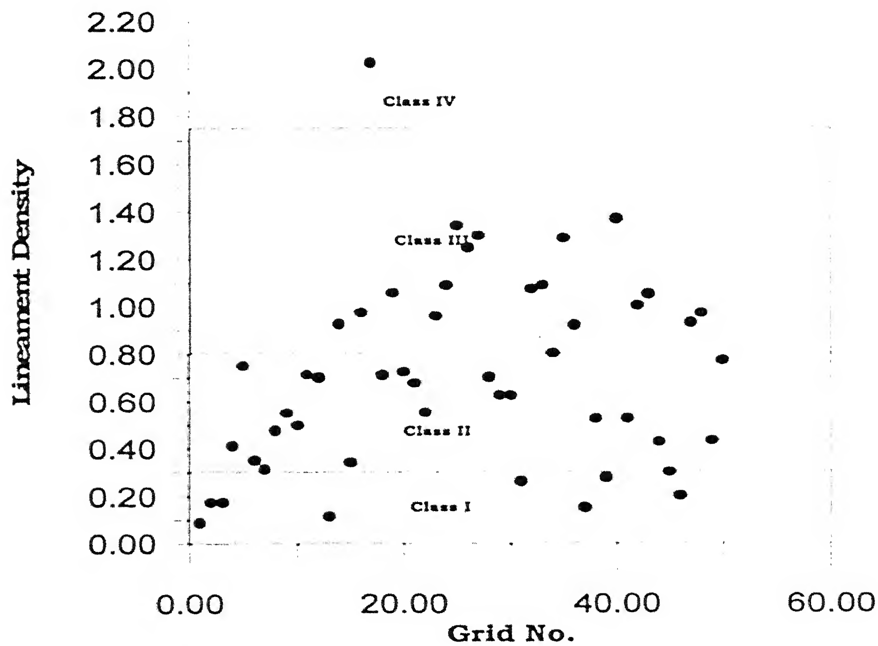


Figure 4.3 Gridwise lineament density distribution: Srinagar-Rudraprayag section

Table 4.7 Grid-wise Drainage Density of the Alaknanda Catchment: Rudraprayag-Nandprayag section

1 LD =0.50	2 LD=0.95	3 LD=2.87	4 LD=2.59	5 LD=1.62	6 LD=2.56	7 LD=2.63	8 LD=4.30
9 LD=2.170	10 LD=2.23	11 LD=2.019	12 LD=3.05	13 LD=2.95	14 LD=4.18	15 LD=2.79	16 LD=2.307
17 LD=0.47	18 LD=0.997	19 LD=1.36	20 LD=0.583	21 LD=1.264	22 LD=1.406	23 LD=2.878	24 LD=2.054
25 LD=0.261	26 LD=1.234	27 LD=1.106	28 LD=1.017	29 LD=1.106	30 LD=0.830	31 LD=1.590	
32 LD=0.84	33 LD=0.81	34 LD=1.742	35 LD=1.383	36 LD=1.205	37 LD=0.879	38 LD=0.839	

LD - Lineament density

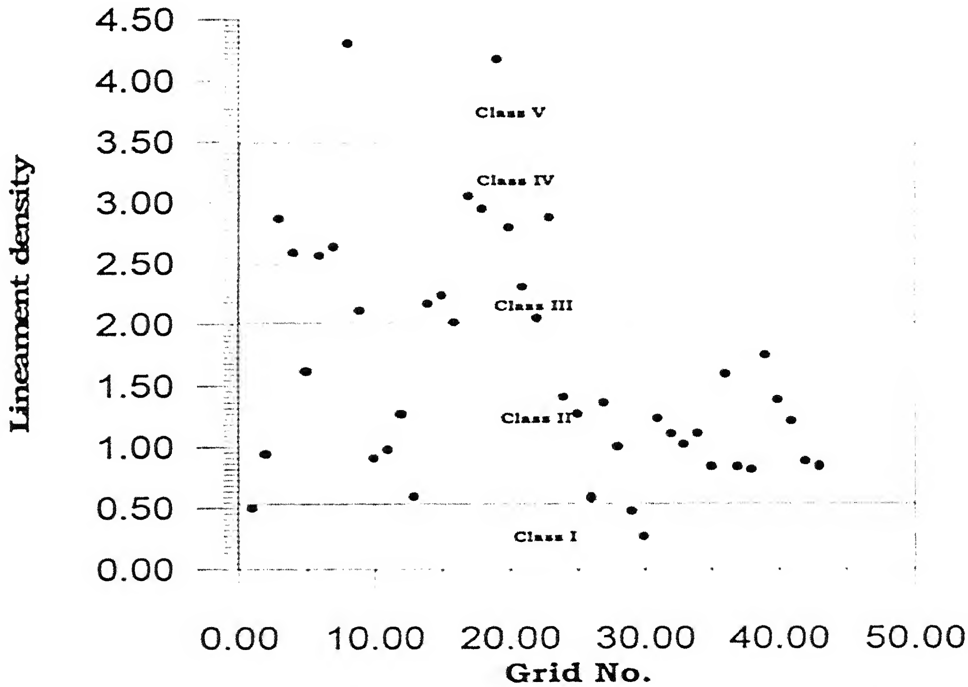


Figure 4.4 Gridwise lineament density distribution: Rudraprayag-Nandprayag section

Table 4.8 Classes of lineament density: Srinagar-Rudraprayag section

Class interval	Class no.	Category
0.00-0.03	1	Low
0.03-0.8	2	Moderate
0.8-1.75	3	High
> 1.75	4	Very High

Table 4.9 Classes of lineament density: Rudraprayag-Nandprayag section

Class Interval	Class no.	Category
0.00-0.06	1	Low
0.06-2.00	2	Moderately low
2.00-2.50	3	Moderately high
2.50-3.50	4	High
>3.50	5	Very High

4.4.6 Slope Map

The slope of a region can be defined as its upward or downward inclination with respect to the horizontal plane. Its variation in different parts of an area indicates the spatial distribution of the slope gradients. The steep slope generally develops in the hard, compact and resistant rock, while the gentle slopes, in general, develops in soft and less resistant rocks.

Slope Map: Srinagar to Rudraprayag

The slope map for Srinagar-Rudraprayag section was obtained from Sarkar (1996) that was derived from a 1: 50,000 topographical map. Initially, the area was divided into number of facets possessing more or less uniform slope direction with natural topographic boundary in the form of ridges and streams. The facets were then divided into number of slope categories on the basis of number of contours and their spacing. For this, number of contour lines per cm of horizontal distance was counted on the topographical map. The slopes are then regrouped into five categories as

follows:

1. escarpment (> 45°)
2. steep slope (35° - 45°)
3. moderately steep slope (25° - 35°)
4. gentle slope (15° -25°)
5. very gentle slope (< 15°)

This slope map for Srinagar-Rudraprayag section was first scanned. Then the slope categories of this map were on screen digitized separately and rasterized on a single image. This image containing all the subsequent slope classes is registered to the base image (Plate 4.15).

Slope map: Rudraprayag to Karnprayag

The slope map for this section was generated with the help of 1: 250,000 topographical map having a contour interval of 500 ft. Since the topographical map was up to Karnprayag only, the slope map for Srinagar-Nandprayag section was generated only up to Karnprayag. The study area in the topographical map was first scanned and then converted into an image format. This image of the topographical map was then registered with the help of ground control points to the base map. The registered the topographical map was screen-digitized at a contour interval of 500 ft. Each of these digitized contours was given a separate identity number and then rasterized. In the database, the actual values of the contours were assigned corresponding to the identity number. Then through the *Assign* module of IDRISI, the actual contour values were assigned to the rasterized image. After this a raster digital elevation model (DEM) is generated from the given set of rasterized contours through

Slope Map: Srinagar to Rudraprayag Section

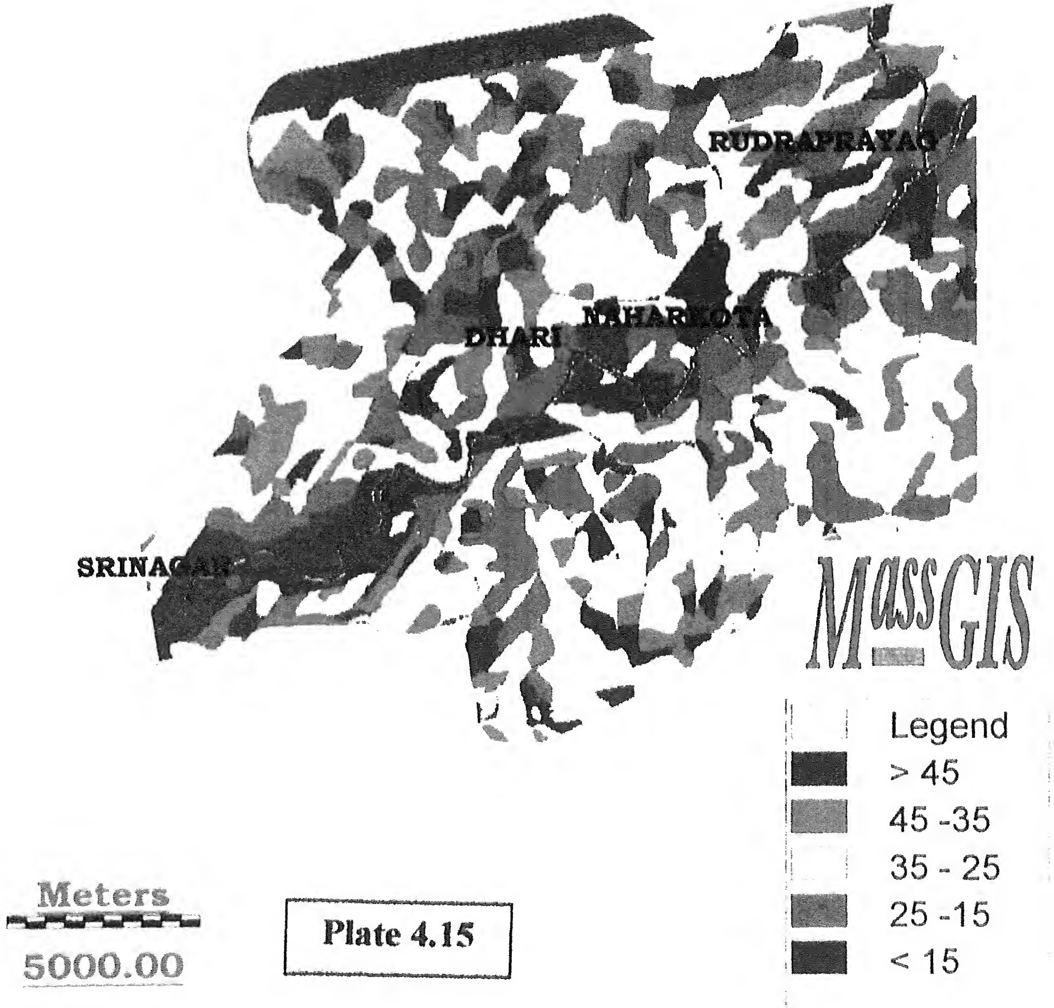


Plate 4.15

the IDRISI module *Intercon* by linear interpolation between contours to produce a faceted model. This DEM was subsequently filtered using mean filtering of IDRISI to produce a smooth 3-D elevation model of the study area catchment. The FCC of the study area is then draped over the 3-D elevation model in different orthographic projections with different viewing angle to get a 3-D view of the valley, terraces, ridges and facets of the study area (Plate 4.16). Although the 3-D model is very crude, as the contour interval is 500 ft, it gives an excellent impression of the topography of the area in relation to the geomorphic features present in the area like valley, terraces, ridges, gullies and channels. From the generated DEM, surface slope was determined by using the *Slope* module of IDRISI. It calculates the maximum slope around each pixel from the local slopes in X- and Y-directions. Only the neighbours above, below, and to either side of the pixel are accounted for in this procedure, called a "rook's case" procedure. A slope map of the study catchment was thus generated through this procedure. The abrupt changes in the nature of the slope and other noises were removed through iterative mean filtering. The final slope map (Plate 4.17) having slope from 0 to 90 degree is then reclassified into 6 categories as given below:

1. Very high steep slope (>75°)
2. High steep slope (60° - 75°)
3. Moderately high steep slopes (60° - 45°)
4. Moderately steep slopes (45° - 30°)
5. Gentle slope (30° -15°)
6. Very gentle slope (<15°)

DEM: Rudraprayag-Karnprayag Section (VD=80, VA=50)

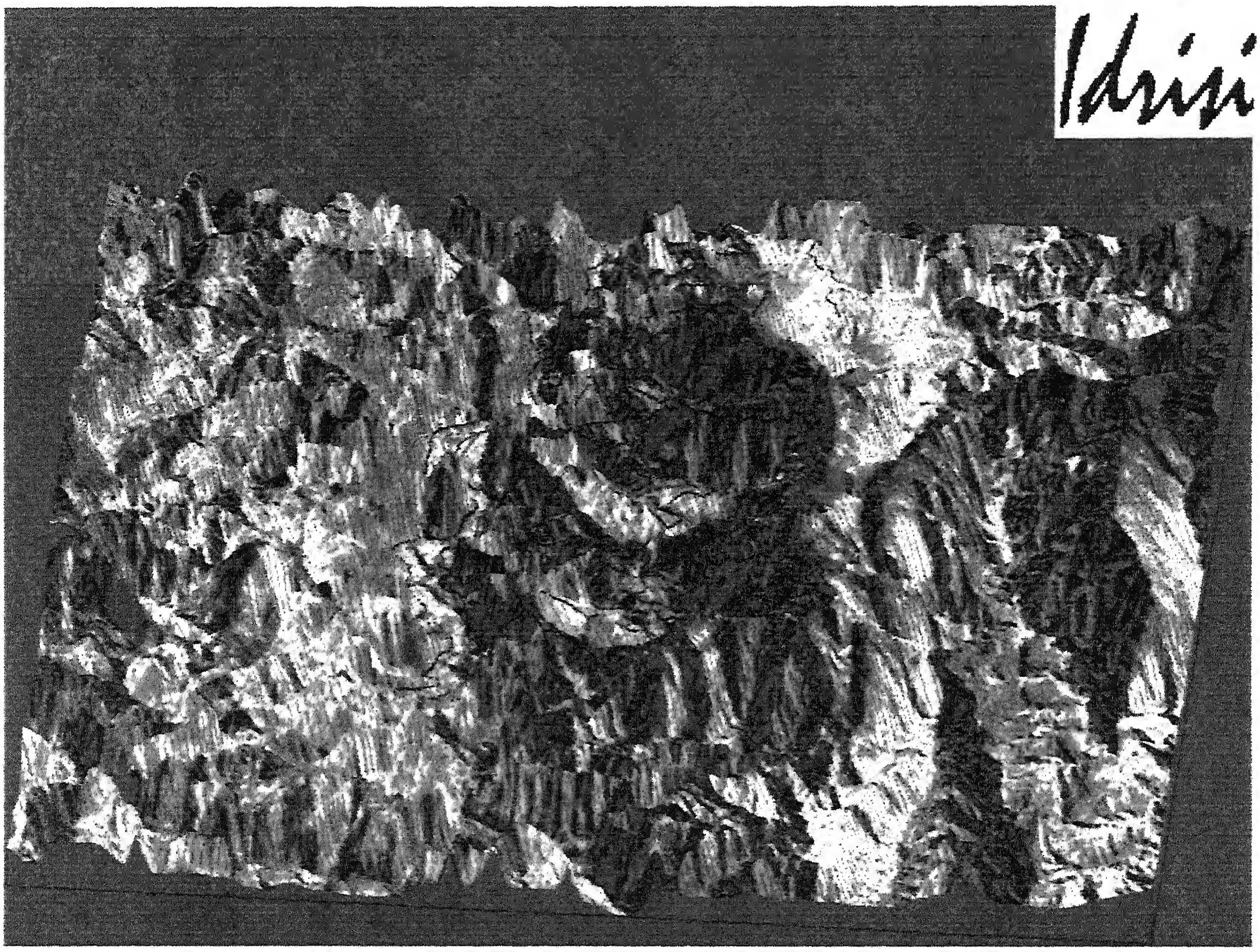
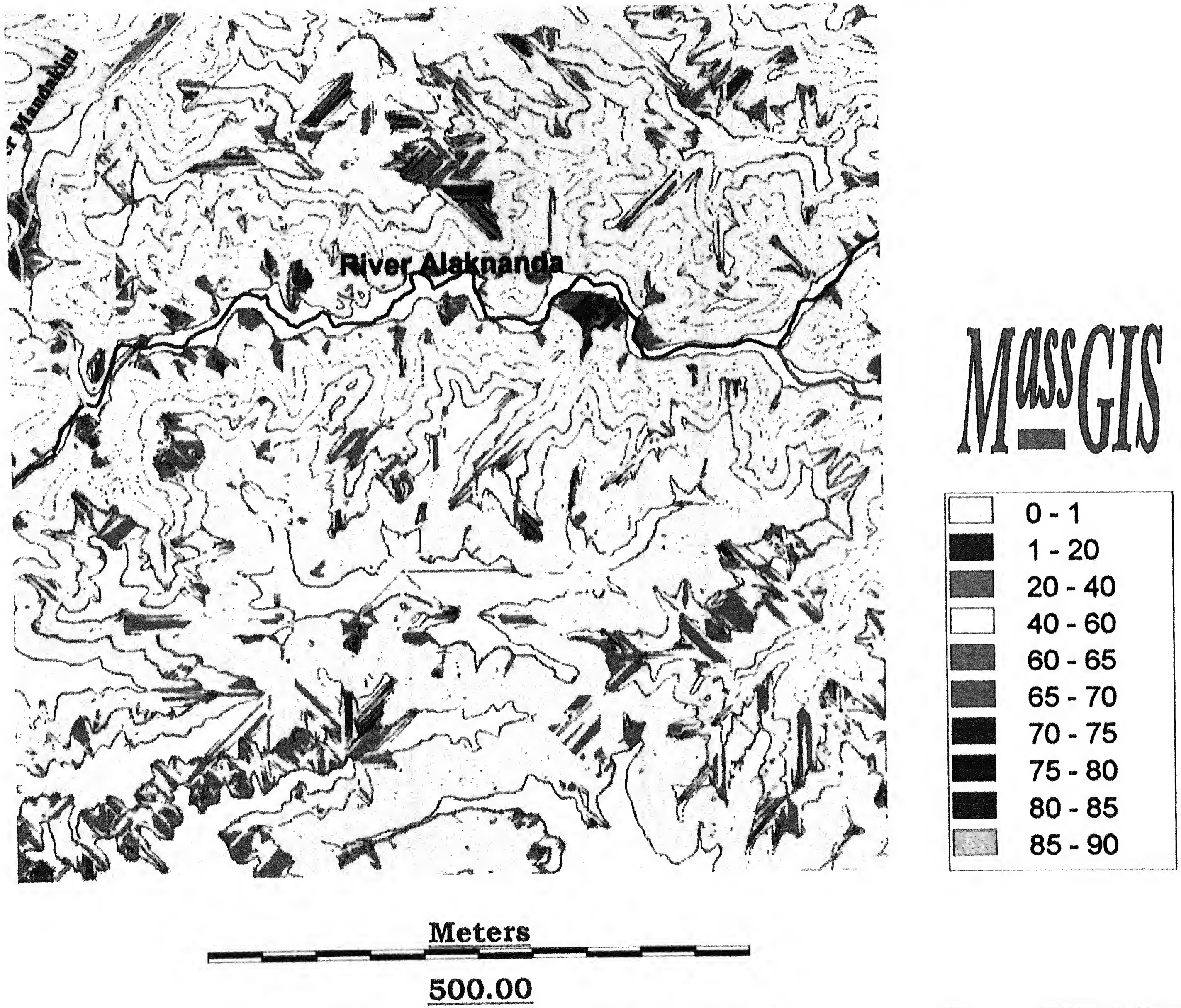


Plate 4.16

Plate 4.17 Slope Map: Rudraprayag-Karnprayag Section



It is worthwhile to mention that the slope classes in the final map produced from Srinagar-Rudraprayag section and Rudraprayag-Karnprayag section are different. This is essentially because of the difference in the resolution of the topographic maps used for generating the slope maps.

4.5 DISCUSSION

This chapter has explained generation of the thematic layers containing data from different sources and resolution. With the help of digital image processing techniques supported by ground reference data and available maps, classified thematic maps for slope, lithology, geomorphology, drainage density, lineament and structural density and vegetation were prepared. The slope data as well as the structural data for the Srinagar-Rudraprayag section is more detailed and of higher resolution compared to that of Rudraprayag- Karnprayag section. The two output maps (slope and lineament density) of the two sections were also produced out of two different techniques. Hence, the slope and lineament maps of Rudraprayag-Karnprayag section contain more regional features, while those of the Srinagar-Rudraprayag section give detailed information of the local geology of the area. The rest of the thematic layers of the two sections are from similar source. Since some of the data sets available in the two different sections are different, further analysis has also been carried out separately for the two sections in the next chapter. Thus the next chapter will highlight manipulation of these data bases after giving suitable quantitative weights to each of the factors and sub-factors controlling erosion in order to produce an erosion intensity map of the study catchment through GIS modeling.

Chapter 5

GIS APPLICATION FOR EROSION INTENSITY MAPPING

A voluminous amount of data sets obtained from various digital image-processing techniques, already discussed in chapter 4, need to be handled in a database for the catchment scale erosion intensity mapping. These data sets contain spatial information in the form of satellite imagery along with map and ground data covering a large geographical region. This was achieved through the manipulation of the data sets created in the form of thematic layer discussed in chapter 4. The objective of this chapter is to illustrate the application of Geographical Information System (GIS) techniques in catchment scale erosion intensity mapping and sediment source delineation by using these manipulated data sets. This was done by using one of the multi-criteria decision-making techniques called Analytic Hierarchy Process (AHP). In this chapter, first a brief discussion on GIS and AHP is presented, followed by the detail discussion on methodology and principles adapted for erosion intensity mapping in the study area. The last two sections of this chapter deal with the results, discussion and validity of the final erosion map.

5.1 GENERAL GIS

As already discussed, an efficient technique is required by means of which the data sets can be stored, retrieved, manipulated, analyzed and displayed. This is the role of Geographic Information System (GIS). Like its commercial counterpart, the Management

Information System (MIS), the GIS is designed to carry out operations on the data stored in its database according to the user's set of specifications. A GIS is thus defined as a means of storing, retrieving, analyzing and displaying spatially related sets of resource data so as to provide management information or to develop a better understanding of the environmental relationship. The chief advantages of the strategy of combining several data sets are three fold (Gupta, 1991):

i. Using multidata, the number of attributes or channels of information is increased, and this would correspondingly enhance the capability of discrimination, identification and categorization.

ii. The collateral data also usually include ground truth data, and this would enable proper labeling of categories.

iii. Interpretation of all the data sets collectively should result in a coherent analysis.

In this thesis, I have used GIS for the identification of sediment source and erosion intensity mapping in the Himalayan Catchment. GIS is a digital database to manage large volume of data from a variety of sources. So, in this type of study, where multidata is available and required for analysis, GIS along with one of the most modern decision making technique, AHP, will serve to aid preliminary sediment production zone identification.

5.2 ANALYTICAL HIERARCHICAL PROCESS

AHP is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of, dependent and independent, qualitative and quantitative information. It is a

methodology to systematically evaluate, often conflicting, qualitative criteria (Saaty, 1980). Like other multi-attribute decision model, AHP also attempts to resolve conflicts and analyze judgements through a process of determining the relative importance of a set of activities or criteria by pairwise comparison of these criteria on 9-point scale (Table5.1). In order to do this a complex problem is first divided into a number of simpler problems in the form of a decision hierarchy (Erkut and Moran, 1991). AHP is often used to compare the relative preferences of a small number of alternatives concerning an overall goal. Since its introduction in the late 1970s, AHP had been applied in a wide variety of practical settings to complex decision problems. Its ability to rank and quantitatively assess decision alternatives had led to many applications in such areas as health care (Dougherty and Saaty, 1982), politics (Saaty, 1979), urban planning (Cook *et al.*, 1984), space exploration (Bard, 1986) and landfill suitability (Siddiqui *et al*, 1996), potential solid waste disposal sites (Sengupta *et al.*, 1997). AHP is becoming popular in decision-making studies where conflicting objectives are involved. In the recent times Siddiqui *et al.*, (1996) introduced a new method known as Spatial – AHP to identify and rank areas that are suitable for a landfill, using knowledge based user preferences and data contained in GIS maps. Sengupta *et al.* (1997) used GIS technique along with multi-decision making technique, AHP, for preliminary solid waste disposal site selection in Kanpur city.

5.3 METHODOLOGY INVOLVED IN EROSION INTENSITY MAPPING

For the present study, the spatial-AHP technique (integrating the GIS database in the AHP framework) was applied to identify the potential sediment sources by erosion intensity mapping. The spatial AHP involves the following 5 steps: -

1. Identifying the issues, objective or goal.

2. Identifying the decision factors.
3. Structuring them in a decision hierarchy
4. Judging the RIWs of the decision hierarchy elements
5. Aggregating these measures in order to calculate Erosion Intensity Index (EII) of the alternatives
6. Ranking the categories according to EII.

5.3.1. Identifying the issues, objectives or goal

The goal or the objective of my thesis is the identification of potential sediment sources by erosion intensity mapping in a Himalayan catchment.

5.3.2. Identifying the Decision Factors

The decision factors which are used to relate attribute to suitability concerning a particular goal, as in this case, selecting factors controlling erosion intensity in the study area. The primary factors, which have been considered in this study, as already mentioned in earlier chapters, are slope, lithology, geomorphology, vegetation, structural and lineament density and drainage density.

Once the decision factors are selected, sub-factors and even sub-sub-factors are identified to describe these criteria better. For example the geomorphological class was further subdivided into five subclasses as follows:

i. valley
ii. terraces
iii. alluvial fan
iv. channel bars
v. gully

Similarly the other decision factors like slope, lithology, lineament density, drainage density are sub-divided into sub-factors.

5.3.3 Decision hierarchy

The decision factors are arranged in a decision hierarchy consisting of number of levels. The first level of the hierarchy represents the goal, while the rest of the levels describe the factors and sub-factors in increasing details.

For the present study, the decision hierarchy used is shown schematically in Figure 5.1. The decision factors related to erosion in the study area catchment mentioned in the earlier section are then arranged in a decision hierarchy

The Level 1 of the hierarchy represents the goal or objective of the present study, i.e., erosion intensity mapping and potential sediment source delineation in the Alaknanda catchment.

The major decision factors, Level 2, are the factors controlling the erosion in the study area within the Alaknanda catchment and they are listed as follows:

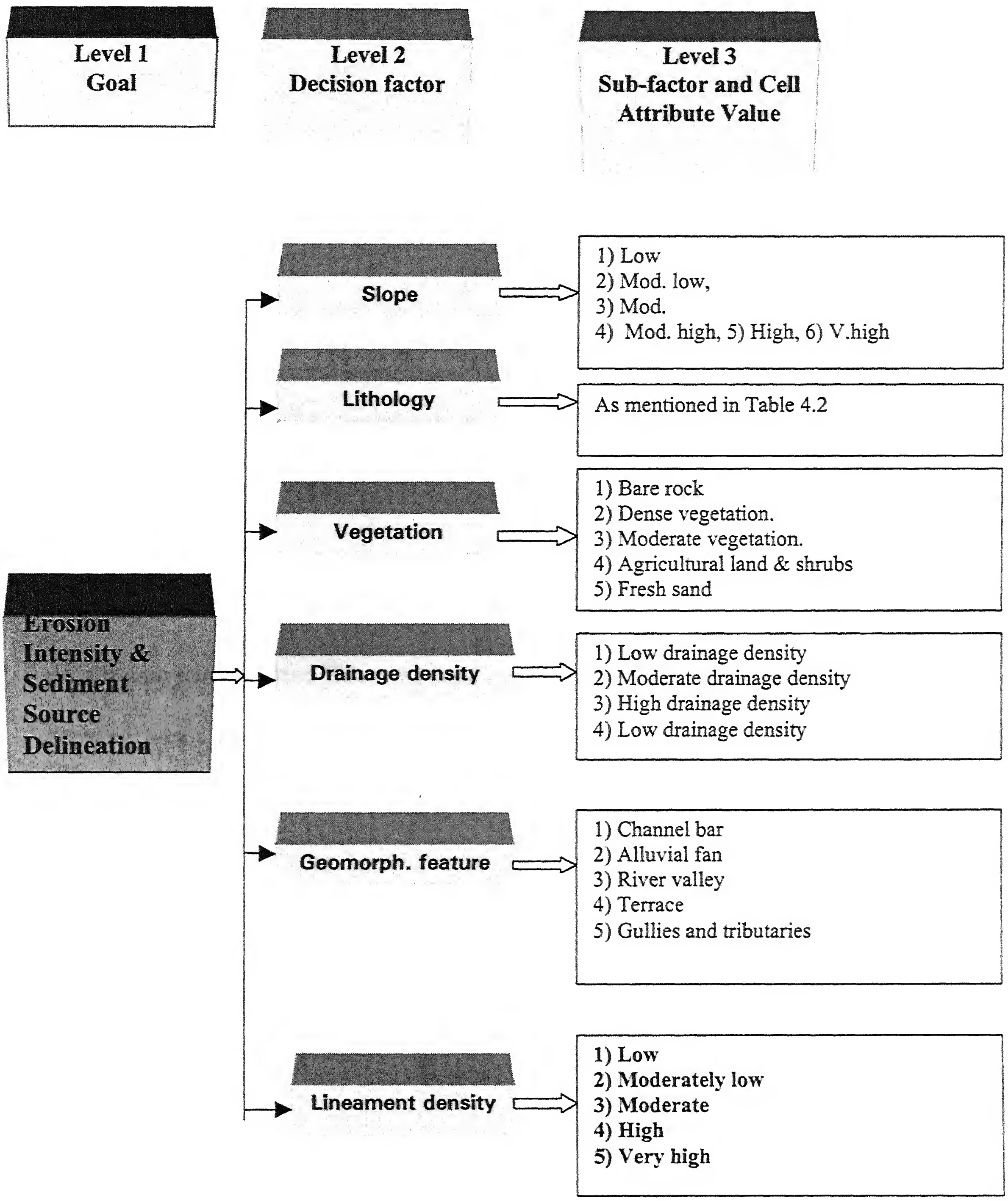
1. slope,
2. lithology,
3. vegetation
4. drainage density
5. geomorphological structures and
6. lineament density.

Level 3 represents the different sub–factors of each Level 2 decision factor. For example, the Level 2 decision factor, vegetation, which is one of the controlling factors for erosion intensity, as identified in the study catchment area are sub classified as follows: -

1. fresh sand/ no vegetation,
2. bare rock ,
3. agricultural lands/shrubs
4. moderate vegetation
5. dense vegetation

Similarly other level 2 decision factors are subdivided according to available information and data of the thematic layers given in chapter 4. Thus, the construction of these levels is qualitative and depends on the decision-maker's understanding of the problem.

Figure 5.1 Decision Hierarchy for Erosion Intensity Index Ranking



5.3.4 Relative Importance Weight

The RIWs are the normalized eigen vectors corresponding to the maximum eigen values of the pairwise comparison matrices constructed at each level of the decision hierarchy. The RIW assigned to each hierarchy element was determined by normalizing the eigen vector of the decision matrix. Eigen vectors were then estimated by multiplying all the elements in a row and taking the nth root of the product, where n is the number of row elements (Saaty, 1980). Normalization of the eigen vectors was accomplished by dividing each eigen vector elements to the decision factor.

Thus for the hierarchy represented in the Figure 5.1, the relative importance weight of level 2 decision factors like slope, lithology, vegetation, drainage density, geomorphological structures, lineament density was determined by comparing the decision factors pairwise. This was followed by pairwise comparison within each level 3-decision factor. As already mentioned in section 5.2 an attempt has been made to resolve conflicts and analyze judgement by a process of determining the relative importance of decision factors related to this thesis by pairwise comparison of these factors on a nine point scale given Table 5.1.

Table 5.1 Analytic Hierarchy Measurement Scale (Saaty, 1980)

Reciprocal Measure of Intensity of Importance	Definition	Explanation
♦ 1	Equal importance	Two activities contribute equally to the objective
♦ 3	Weak importance of one over another	Experience and judgement slightly favor one over another
♦ 5	Essential or strong importance	Experience and judgement favor one activity over another
♦ 7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
♦ 9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
♦ 2, 4, 6, 8	Intermediate value between two adjacent judgements	When compromise is needed
♦ Reciprocal of the above	If the activity *i* have one of the above non zero numbers assigned to it when compared to the activity *j*, then *j* has the reciprocal value when compared with *i*.	

The decision factors, the sub-factors or cell attributes are generally arranged into a set of decision matrices. Table 5.2 shows such a matrix of the level 2 decision-factors. In this table, the relative weightages were assigned to each of the thematic layers for producing the final GIS composite layer is computed taking the following into consideration: -

- The value in the cells of the column 2 of Table 5.2 suggests the importance of the factor slope relative to the other level 2 decision factors. The first value of the column 2, is the importance of the factor slope relative to slope in the lieu of erosion Intensity. Consequently, a value of 1 was assigned indicating equal preference according to the Table 5.1. Therefore the entire diagonal matrix in the Table 5.2 is unity since it compares identical factors. All other cells contains different values depending on the amount of preference to erosion intensity of one decision factor in comparison to the other factor of the pair within the study area.

- The first value in the column 3 shows the importance of slope compared to lithology in the study area. The slope and lithology can both act as potential sediment production factors. Slope categories in the slope map of the study area Plates 4.14 and 4.16 of chapter 4 represents the valley wall slope and the facets of the ridges within the catchment. So through these slopes - the gullies, streams and tributaries flow. The extent of erosion and hence sediment production by the above factors obviously depends on slope. The intensity of erosion due to slope would be more than the factor lithology, as observed from the field investigation. So slope was weakly preferred than lithology in terms of sediment production and so the value assigned to this cell is 3.

- The amount of sediment brought through slopes will be much higher than that from a region having high drainage density or less/no vegetation or having a number of unconsolidated geomorphological features. So, slope would have a strong preference in controlling sediment production compared to the contribution by drainage density, geomorphological features or vegetation. So all these cells in the 1st row are given a preference value of 5.

- Lineament Density as already discussed in chapter 4 was prepared on the basis of the geomorphic lineaments and structural features present in the study area. These structural and geomorphic lineaments are actually of same scale as that of the image. So although they appear to be very closely spaced in the image due to the scale, but actually they are kilometers apart. Hence the Lineament Density determined in this scale will actually not imply the shattering behavior of the rock that enhances sediment production directly, but would rather highlight the blocky characteristic of the rock, which would enhance landslides and thus act as an indirect source of sediment. Hence slope which directly affects erosion and sediment production was given a much stronger preference than lineament density, which act as an indirect source of sediment production.

Using similar logic rest of the level 2 and level 3 decision factors matrices are computed as given in Table 5.2 and Table 5.3.

- After assigning the reciprocal intensity values to the different decision factors, relative importance to each hierarchy element was determined by normalizing the eigen vector of the decision matrix. eigen vector values are estimated by multiplying all the elements in a row and taking the n^{th} root of the products, where n is number of row elements (Saaty, 1980). For the first row of Table 5.3 the eigen element of the slope was estimated as follows:

$$\boxed{EstimatedEE(slope) = \sqrt[6]{1*4*5*5*5*6} = 3.80}$$

- Normalization of the eigen vector was accomplished by dividing each eigen vector element by the sum of all the eigen vector elements in a particular matrix, this is known as the Relative Importance Weight (RIW) for a particular decision factor. For Slope the RIW is computed as follows from Table 5.3:

$$RIW\ (Slope) = 3.80/(3.80 + 1.80 + 1.20 + 0.78 + 0.62 + 0.25) = 0.45$$

Similarly all the eigen vector values and the RIWs of the level 2 and level 3 decision factors were calculated and as shown in Tables 5.2 and 5.3.

Table 5.2 Calculation of Relative Importance Weightage for Level 2 Decision Factor

Decision Factors	Pairwise Comparison						EEE*	RIW
	Slope	Lithology	DD*	G.S*	Veg*	LD*		
Slope	1	4	5	5	5	6	3.80	0.45
Lithology	1/4	1	3	3	3	5	1.80	0.21
DD*	1/5	1/3	1	3	3	5	1.20	0.14
G. S*	1/5	1/3	1/3	1	2	5	0.78	0.09
Veg	1/5	1/3	1/3	1/2	1	5	0.62	0.07
LD*	1/6	1/5	1/3	1/5	1/5	1	0.25	0.02

Note: DD* = drainage density
GS* = geomorphological features
Veg* = vegetation
LD* = lineament density
EEE*= estimated eigen element

Table 5.3 Calculation of Relative Importance Weightage for Level 3 sub-factors

1a. Slope: Srinagar to Nandprayag section

Decision Factors	Pairwise Comparison					EEE*	RIW
	> 45°	45°-35°	35°-25°	25°-15°	< 15°		
> 45°	1	4	5	7	9	4.17	0.51
45°-35°	1/4	1	4	6	8	2.17	0.27
35°-25°	1/5	1/4	1	5	7	1.12	0.14
25°-15°	1/7	1/6	1/5	1	5	0.47	0.06
< 15°	1/9	1/8	1/7	1/5	1	0.21	0.02

Note: EEE* = estimated eigen element

1b. Slope: Rudraprayag to Nandprayag section

Decision Factors	Pairwise Comparison						EEE*	RIW
	90°-75°	75°-60°	60°-45°	45°-30°	30°-15°	15°-0°		
90°-75°	1	3	5	7	8	9	4.43	0.45
75°-60°	1/3	1	3	5	7	8	2.56	0.26
60°-45°	1/5	1/3	1	4	6	7	1.49	0.15
45°-30°	1/7	1/5	1/4	1	5	7	0.79	0.08
30°-15°	1/8	1/7	1/6	1/5	1	7	0.41	0.04
15°-0°	1/9	1/8	1/7	1/7	1/7	1	0.18	0.01

Note: EEE* = estimated eigen element

2. Lithology: Srinagar to Nandprayag section

Decision factors	Pairwise Comparison									EEE*	RIW
	1	2	3	4	5	6	7	8	9		
1	1	2	3	4	5	6	7	8	9	4.15	0.31
2	1/2	1	2	3	4	5	6	7	8	3.01	0.22
3	1/3	1/2	1	2	3	4	6	7	8	2.23	0.16
4	1/4	1/3	1/2	1	2	3	4	5	6	1.46	0.11
5	1/5	1/4	1/3	1/2	1	2	3	4	5	1	0.07
6	1/6	1/5	1/4	1/3	1/2	1	2	3	4	0.68	0.05
7	1/7	1/6	1/6	1/4	1/3	1/2	1	2	3	0.46	0.03
8	1/8	1/7	1/7	1/5	1/4	1/3	1/2	1	2	0.33	0.02
9	1/9	1/8	1/8	1/6	1/5	1/4	1/3	1/2	1	0.24	0.018

Note: EEE* = estimated eigen element

3. Drainage density: Srinagar to Nandprayag section

Decision factors	Pairwise Comparison				EEE*	RIW
	> 4.5	4.5 – 3.5	3.5 - 2	< 2		
> 4.5	1	5	8	9	4035	0.626
4.5 – 3.5	1/5	1	6	9	1.8	0.26
3.5 – 2	1/8	1/6	1	6	0.59	0.088
< 2	1/9	1/9	1/6	1	0.21	0.030

Note: EEE* = estimated eigen element

4a. Geomorphology: Srinagar to Rudraprayag section

Decision Factors	Pairwise comparison				EEE*	RIW
	Gully	Terrace	Valley	Channel Bar		
Gully	1	3	5	9	3.41	0.55
Terrace	1/3	1	4	9	1.86	0.30
Valley	1/5	1/4	1	7	0.77	0.12
Channel Bar	1/9	1/9	1/7	1	0.20	0.03

Note: EEE* = estimated eigen element

4b. Geomorphology: Rudraprayag to Nandprayag Section

Decision Factors	Pairwise Comparison					EEE*	RIW
	Gully	Terrace	Valley	Alluvial Fan	Channel Bar		
Gully	1	3	5	8	9	4.04	0.48
Terrace	1/3	1	4	8	9	2.49	0.30
Valley	1/5	1/4	1	7	9	1.25	0.15
Alluvial Fan	1/8	1/8	1/7	1	5	0.41	0.049
Channel Bar	1/9	1/9	1/9	1/5	1	0.19	0.023

Note: EEE* = estimated eigen element

5. Vegetation: Srinagar to Nandprayag

Decision Factors	Pairwise Comparison					EEE*	RIW
	FS*	AG*	MV*	DV*	BR*		
FS*	1	3	5	7	9	3.94	0.47
AG*	1/3	1	5	7	9	2.54	0.31
MV*	1/5	1/5	1	5	9	1.12	0.13
DV*	1/7	1/7	1/5	1	7	0.49	0.06
BR*	1/9	1/9	1/9	1/7	1	0.18	0.02

Note: FS* = fresh sand
AG* = agricultural land and shrubs
MV* = moderarate vegetation
DV* = dense vegetation
BR* = bare rock
EEE* = estimated eigen element

6. Lineament Density: Srinagar to Nandprayag

Decision Factors	Pairwise Comparison					EEE*	RIW
	> 3.5	3.5 – 2.5	2.5 – 1.5	1.5 – 0.6	< 0.6		
> 3.5	1	5	6	7	9	4.52	0.52
3.5 – 2.5	1/5	1	5	7	9	2.29	0.26
2.5 – 1.5	1/6	1/5	1	5	7	1.17	0.13
1.5 – 0.6	1/7	1/7	1/5	1	5	0.46	0.05
< 0.6	1/9	1/9	1/7	1/5	1	0.20	0.02

Note: EEE* = estimated eigen element

5.3.5 Erosion Intensity Index (EII)

The EII for each pixel was determined by aggregating RIWs at each level of the hierarchy. EII for all raster cells were determined simultaneously using GIS Map Algebra of IDRISI module. Higher the EII value the higher the sediment production for that pixel.

EII was calculated by multiplying the RIWs of level 3-decision factor by the associated RIWs of the level 2 factors and summing the values of all grouped elements. Since our problem is defined in three level hierarchies, the simplified equation for 3 level hierarchy is:

$$EII = \sum_{i=1}^{N_2} \left[\left(RIW_i^2 \right) * \left(RIW_{ij}^3 \right) \right]$$

EII = erosion intensity index,

N_2 = the number of level 2 decision factor,

RIW_i^2 = relative importance weight of level 2 decision factor i.

RIW_{ij}^3 = relative importance weight of level 3 sub-factor j of level 2 decision factor i.

If the decision hierarchy has more or fewer levels, the formula must be modified appropriately.

5.4 RESULTS

The EII values as obtained from the above equation for the Rudraprayag-Karnprayag and Srinagar-Rudraprayag are plotted as histograms in Figure 5.2 and Figure 5.3 and the frequency distribution Tables 5.4 and 5.5 respectively.

Figure 5.2 Histogram of the Erosion Intensity Map of Alaknanda Catchment: Rudraprayag-Karnprayag

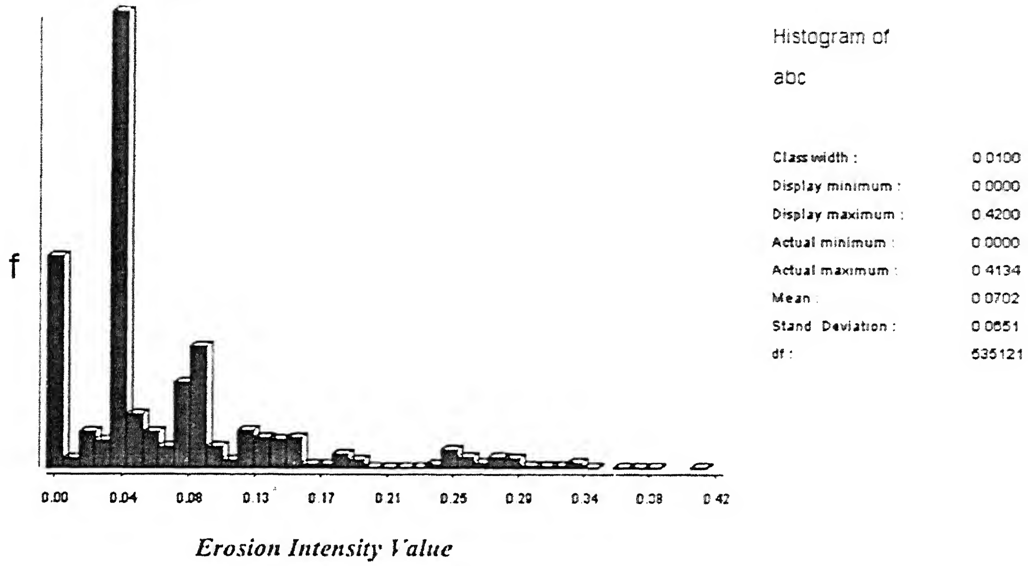


Figure 5.3 Histogram of the Erosion Intensity Map of Alaknanda Catchment: Srinagar-Rudraprayag

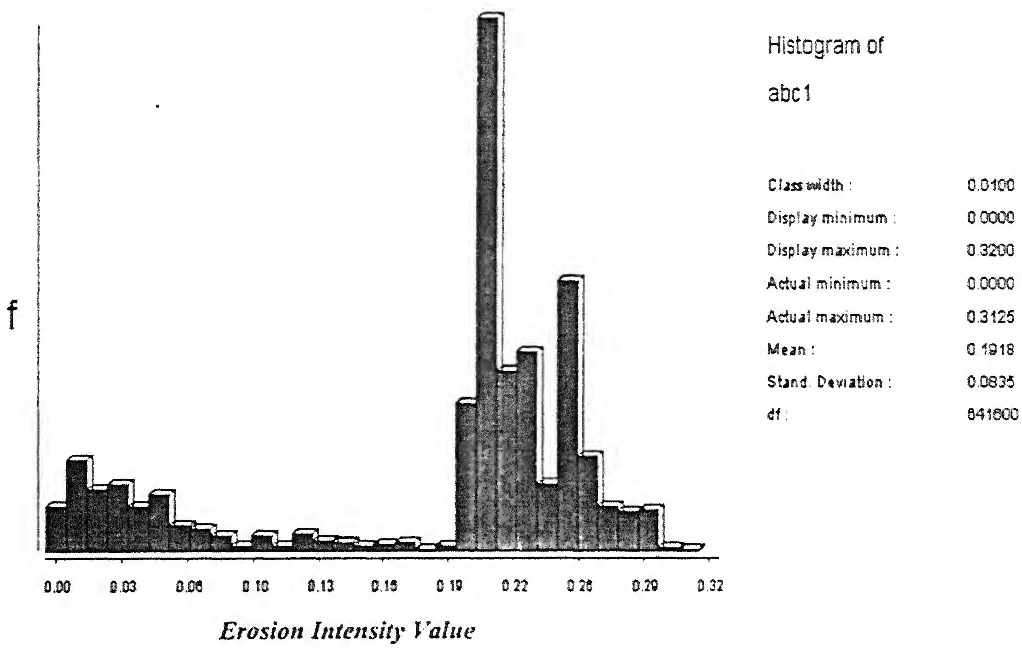


Table 5.4 Frequencies of the different values of Erosion Intensity ranging from 0.0 to 0.42 of Rudraprayag to Karnprayag

Class Lower	Limit Upper	Limit	Freq.	Prop
0	0.0000	0.0099	86580	0.1618
1	0.0100	0.0199	3510	0.0066
2	0.0200	0.0299	14567	0.0272
3	0.0300	0.0399	11077	0.0207
4	0.0400	0.0499	186740	0.3490
5	0.0500	0.0599	21528	0.0402
6	0.0600	0.0699	14723	0.0275
7	0.0700	0.0799	8577	0.0160
8	0.0800	0.0899	34800	0.0650
9	0.0900	0.0999	50132	0.0937
11	0.1100	0.1199	3359	0.0063
12	0.1200	0.1299	15197	0.0284
13	0.1300	0.1399	12401	0.0232
14	0.1400	0.1499	11532	0.0216
15	0.1500	0.1599	12286	0.0230
16	0.1600	0.1699	1330	0.0025
17	0.1700	0.1799	1549	0.0029
18	0.1800	0.1899	5509	0.0103
19	0.19000	.1999	3133	0.0059
20	0.2000	0.2099	320	0.0006
21	0.2100	0.2199	48	0.0001
22	0.2200	0.2299	138	0.0003
23	0.2300	0.2399	299	0.0006
24	0.2400	0.2499	1555	0.0029
25	0.2500	0.2599	7245	0.0135
26	0.2600	0.2699	4107	0.0077
27	0.2700	0.2799	1964	0.0037
28	0.2800	0.2899	4141	0.0077
29	0.2900	0.2999	3468	0.0065
30	0.3000	0.3099	896	0.0017
31	0.3100	0.3199	1012	0.0019
32	0.3200	0.3299	633	0.0012
33	0.33000.	3399	1627	0.0030
34	0.34000.	3499	419	0.0008
35	.3500	0.3599	0	0.0000
36	0.3600	0.3699	135	0.0003
37	0.3700	0.3799	26	0.0000
38	0.3800	0.3899	19	0.0000
39	0.3900	0.3999	0	0.0000
40	0.4000	0.4099	0	0.0000
41	0.4100	0.4199	4	0.0000

Table 5.5 Frequencies of the different values of Erosion Intensity ranging from 0.0 to 0.32 of Srinagar to Rudraprayag

Class	Lower Limit	Upper Limit	Frequency	Proportion
0	0.00000	0.099	13189	0.0206
1	0.0100	0.0199	27397	0.0427
2	0.0200	0.0299	18343	0.0286
3	0.0300	0.0399	20314	0.0317
4	0.0400	0.0499	13161	0.0205
5	0.0500	0.0599	16734	0.0261
6	0.0600	0.0699	7660	0.0119
7	0.0700	0.0799	6305	0.0098
8	0.0800	0.0899	4191	0.0065
9	0.0900	0.0999	1084	0.0017
10	0.1000	0.1099	4143	0.0065
11	0.1100	0.1199	1193	0.0019
12	0.1200	0.1299	4663	0.0073
13	0.1300	0.1399	2484	0.0039
14	0.1400	0.1499	2394	0.0037
15	0.1500	0.1599	1131	0.0018
16	0.1600	0.1699	1495	0.0023
17	0.1700	0.1799	1975	0.0031
18	0.1800	0.1899	255	0.0004
19	0.1900	0.1999	928	0.0014
20	0.2000	0.2099	44772	0.0698
21	0.2100	0.2199	163556	0.2549
22	0.2200	0.2299	55010	0.0857
23	0.2300	0.2399	60836	0.0948
24	0.2400	0.2499	20297	0.0316
25	0.2500	0.2599	82164	0.1281
26	0.2600	0.2699	28319	0.0441
27	0.2700	0.2799	13131	0.0205
28	0.2800	0.2899	11612	0.0181
29	0.2900	0.2999	12057	0.0188
30	0.3000	0.3099	801	0.0012
31	0.3100	0.3199	7	0.0000

5.5 SUITABILITY RANK

The incorporation of the non-exclusionary criteria yields the final EII for each pixel. Threshold values, on the basis of histogram distribution, were incorporated for the purpose of classifying these pixels into groups. Then with the help of the IDRISI module "User – Defined Reclassification," the final EII Image was reclassified into 10 classes (Plates 5.1 and 5.2). Pixels with values between two thresholds were grouped and identified as more susceptible to erosion and sediment production than those pixels lying

in the lower group and vice versa. Then these groups were ranked accordingly; higher value signifies more susceptibility to erosion and sediment production and vice versa.

5.6 DISCUSSION

The final outputs obtained through GIS by AHP analysis in two different sections are shown in Plates 5.1 and 5.2. From the final erosion intensity maps of the study area following observations can be recorded along with corresponding validation with the ground data:

1. It is evident from the images that the final Erosion Intensity Map (EIM) of Rudraprayag to Karnprayag gives idea of erosion intensity of the whole area at a regional scale. On the contrary, the Erosion Intensity Map of Srinagar – Rudraprayag section gives an overall idea of the erosion intensity and potential sediment production areas.

2. Srinagar-Rudraprayag section of the Erosion Intensity Map high erosion intensity can easily be identified and matched with the field observations as follows:

♦ All along the river valley in the Srinagar-Rudraprayag section the sediment production is very highest (Plate 5.1) because of the presence of low fluvial terraces all along the valley. The terraces, as already mentioned in the Chapter 3, are affected by tremendous amount of riparian slip particularly in Srinagar - Rudraprayag section that is evident from the Plate 3.5. So these terraces act as the most significant sediment sources.

Erosion Intensity Map: Srinagar to Rudraprayag Section

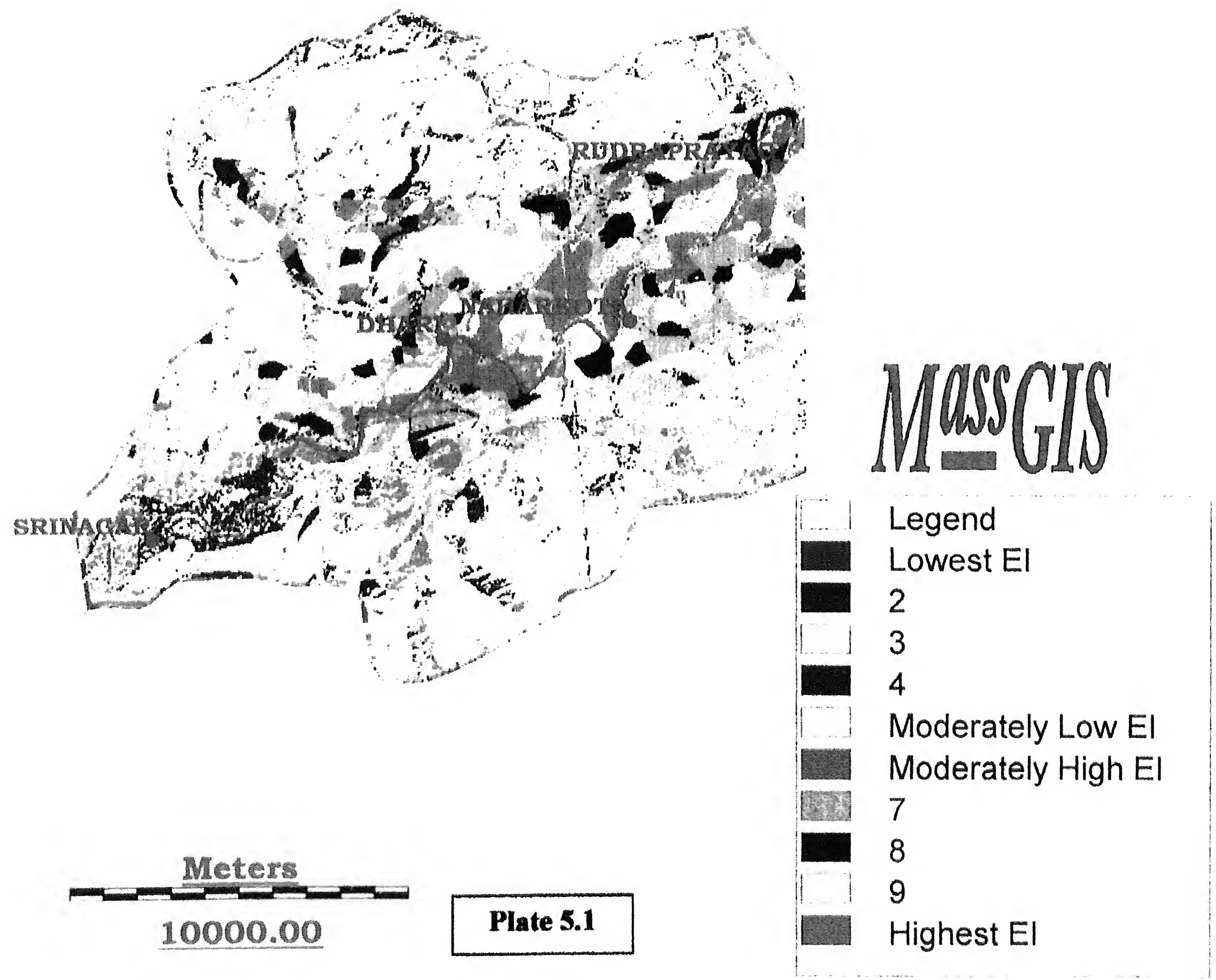
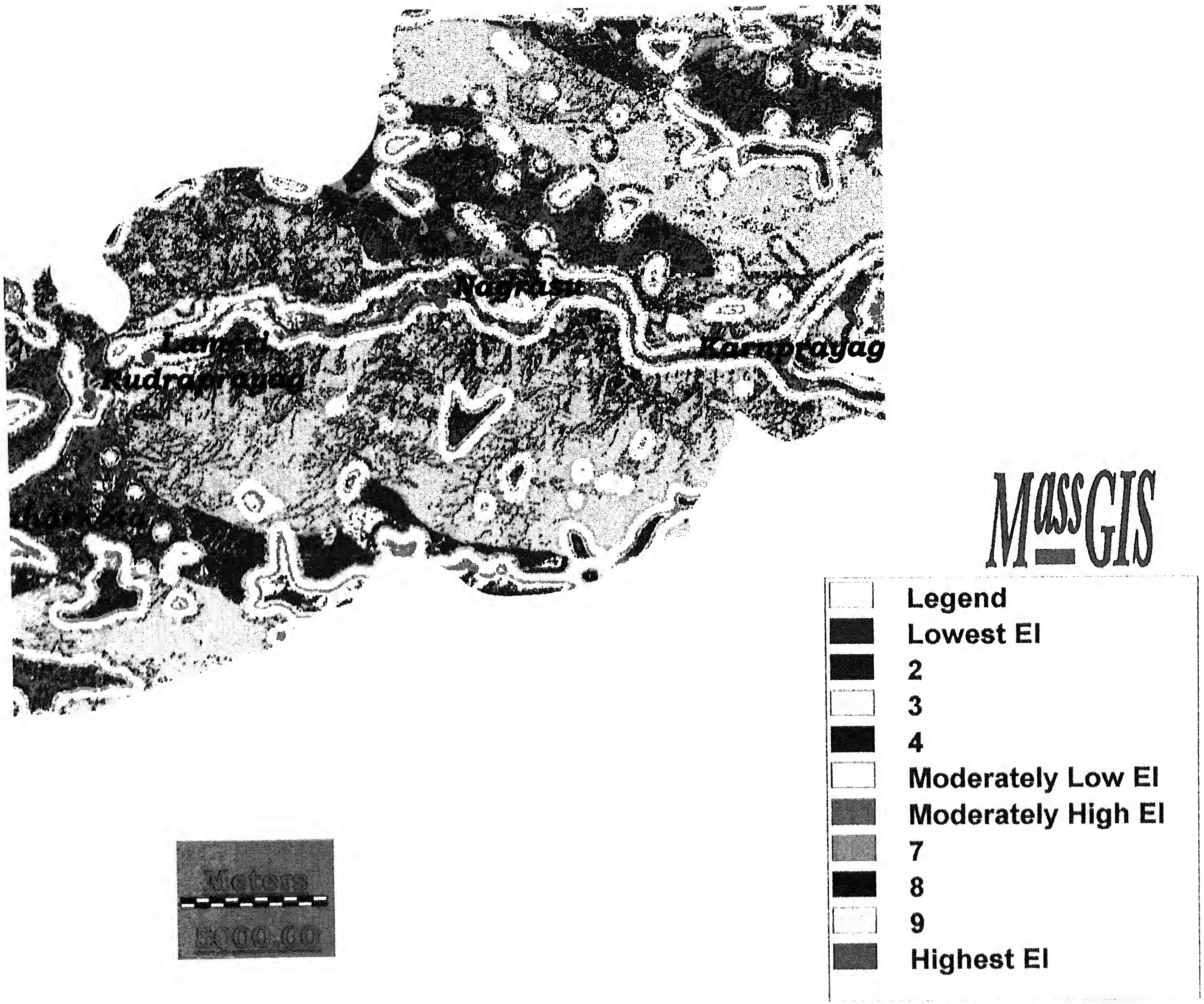


Plate 5.1

Plate 5.2 Erosion Intensity Map: Rudraprayag-Karnprayag Section



- In this section a large number of large-scale landslides are located along the main Alaknanda River. Moreover many of the landslides are also present at the source of many tributaries and gullies as also observed in the field Plate 3.9. These landslides are very active in sediment production. Categories 7, 8 and 9 which are moderately high sediment production zones, match with most of the significant landslides of these section as identified in the field and it also nearly matches with the landslide map of this section as shown in Figure 3.1.

- Srinagar as indicated from the Erosion Intensity Map is having a very low sediment production zone, leaving aside the area near the valley, inspite of having very well developed significant terrace. This indicates that human settlements, comparatively much denser compared to other high altitude region of this area, play a vital role in controlling sediment production in this area. So EI map of the Srinagar–Rudraprayag section gives a much detail and localized idea of potential sediment production areas or high erosion intensity zone.

3. In the Rudraprayag-Karnprayag section the final reclassified Erosion Intensity Map was also divided into 10 classes. The following observations are recorded from this section of the erosion map:

- The erosion Intensity of the Rudraprayag-Karnprayag section all along the river valley is moderate (category 5 and less) in contrast to Srinagar-Rudraprayag section, which shows highest erosion intensity along the valley. In this section the valley is much closed similar to a gorge as evidenced from the

field and devoid of terraces, leaving few locations such as Nagrasu where the Erosion Intensity has increased a lot and falls in the category 7. So large amount of sediment production all along the valley by riparian slip is missing in this section.

- From the field survey and also from the drainage density map of this section, on an average have a higher DD than Srinagar-Rudraprayag section. In this section of the Alaknanda catchment the gully along with the slope plays an important role in increasing the erosion intensity, along with obviously lithology and structure. As the average slopes of this region are much higher, so in most of the areas within the catchment the flow velocity of the gullies increases and hence the erosion intensity also increases. As a result, the Erosion Intensity Map of this section Plate 5.2 shows much higher erosion intensity and sediment production along the Gully. The erosion intensity increases to higher to highest, as indicated in the erosion intensity map, depending on role of gully along with any other factors like the slope, lithology, lineament Intensity etc. A region where one of these factor increases along the gully, depending upon their importance in the hierarchy ranking, the erosion intensity along the gully also increases.

Chapter 6

SUMMARY AND CONCLUSIONS

The study presented in this thesis has highlighted the use of multi-source database including satellite remote sensing data for erosion studies in a mountainous terrain. The Alaknanda catchment in the Garhwal Himalaya, which is prone to extensive erosion throughout the catchment, was taken as the study area. Numerous erosion-related natural hazards such as landslides, debris flow, flash floods etc. are common in the catchment. The present study has focussed on the identification of factors controlling erosion and sediment production in the Alaknanda catchment. An integrated GIS model has been developed using multi-criteria decision-making technique called Analytic Hierarchical Process (AHP). The final outcome of the study has been an erosion intensity map for parts of the Alaknanda catchment, Garhwal Himalaya.

A variety of data were used for this study including IRS 1B LISS – II data, available geological and structural maps, topographic maps and data collected in the field. Based on the availability of data, the study was carried out in two different sections namely, Srinagar-Rudraprayag section and Rudraprayag-Nandprayag section. The data essentially differed in scale and resolution.

Thematic maps of the factors controlling erosion were prepared/classified on the basis of available data making use of different image processing procedures. All the classified data sets (thematic layers) prepared from different sources at different scales, were then brought to the same scale by registration. Then each of the thematic layers along with its classes was given quantitative weights. These weights were given according to the erosion potential/sediment production potential and by using GIS and

spatial AHP. These data sets were merged using a proper algorithm and the final erosion intensity map of Srinagar-Rudraprayag and Rudraprayag-Karnprayag sections were prepared.

The analysis and interpretation of the maps supplemented with field investigations have shown that slope, lithology, lineament density, geomorphology, vegetation and drainage density are the important parameters controlling erosion potential and sediment production in the Alaknanda catchment. Although the relative dominance of these factors may vary from region to region, slope, lithology, drainage density and geomorphology are the most important factors followed by vegetation and lineament density. The erosion susceptibility at any point is the cumulative effect of all these factors.

In the erosion intensity map of the Srinagar-Rudraprayag section geomorphological features like terraces along with landslides were found to be playing the most dominant role in sediment production. So all landslide prone areas and the zones along river, where the terraces are mainly located, showed a very high erosion intensity in the final map of this section, This result also matches with the field observation. On the contrary, the erosion map of the Rudraprayag-Karnprayag section showed very high sediment production and erosion intensity along the gullies, mainly in the regions having high slopes. In this section terraces are not found to be as abundant as that of earlier section hence the erosion intensity map shows a low erosion intensity value all along the valley except at one or two location where terraces are found to be present in the field.

The resultant erosion map of both the sections thus matches well with field observation. Finally, for the Rudraprayag-Karnprayag section, regional-scale information about erosion intensity and sediment production of the area has been obtained. The erosion map of Srinagar-Rudraprayag on the other hand gives much detailed and localized idea of the sediment production zones. In the Rudraprayag-Karnprayag section,

the slope map and lineament map was prepared from a regional scale data with much less resolution. In comparison, the slope and lineament data in Srinagar-Rudraprayag section were available at a larger scale. The rest of the data sets used in both the sections are same. So due to the change in resolution in these two data sets, the overall appearance of the erosion intensity map has changed significantly in the respective sections. Thus it can be concluded that the approach used in the Rudraprayag to Karnprayag is useful for reconnaissance survey while in the Srinagar-Rudraprayag section where some large scale and detailed data is used, detailed erosion intensity and sediment production map can be produced. Detailed field survey could be subsequently used to refine the regional erosion intensity map of the same area and to help in identification and location of the specific potential sediment production zones.

It is concluded that the factors and processes controlling erosion and sediment production in a Himalayan catchment like Alaknanda are very complex. The work presented in this thesis can be significantly improved if maps and spatial data at a larger scale are available. The following aspects need further attention to unravel the complexities of the problem:

(i) Factors such as channel gradient and river discharge should be considered for a more accurate erosion intensity analysis.

(ii) Apart from drainage density, more geomorphometeric parameters, particularly the area and slope parameters, may be added to the model.

(iii) High resolution DEM will improve the erosion intensity model immensely. This can be generated either through large scale maps or through high resolution remote sensing data with significant overlaps.

(iv) The erosion intensity model should be validated through actual measurements of sediment discharge at important confluences. Long-term sediment discharge data throughout the reaches of the Alaknanda river may prove to be of immense value.

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